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Part A

ECOLOGY OF THE
PINYON-JUNIPER TYPE OF
THE COLORADO PLATEAU
AND THE BASIN
AND RANGE PROVINCES

OF LAND MANAGEMENT—UTAH AGRICULTURAL EXPERIMENT STATION

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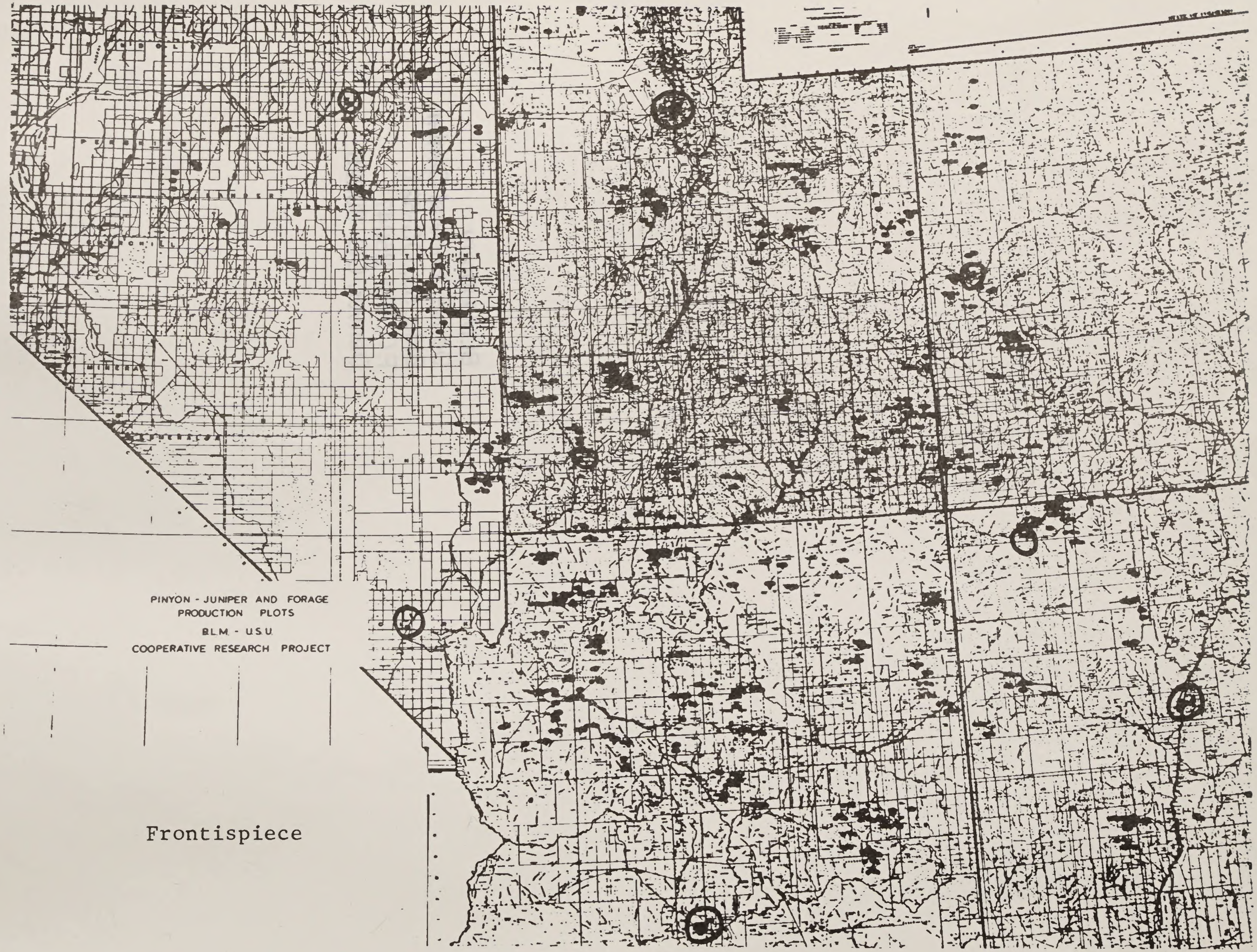
PINYON - JUNIPER AND FORAGE
PRODUCTION PLOTS
B.L.M. - U.S.U.
COOPERATIVE RESEARCH PROJECT

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MANAGEMENT ALTERNATIVES FOR PINYON-JUNIPER WOODLANDS

A. Ecological Phase:

"The Ecology of the Pinyon-Juniper Type of the Colorado Plateau and the Basin and Range Provinces"

T. W. Daniel, Professor of Forestry

R. J. Rivers, Forester

H. E. Isaacson, Range Conservationist

E. J. Eberhard, Range Conservationist

A. D. LeBaron, Economist

A cooperative project of the Bureau of Land Management
and the Utah Agricultural Experiment Station

Logan July 1, 1966

PREFACE

The genesis of the research reported in this volume and in the volume entitled "Economics of Pinyon-Juniper Management," was in the deliberations of Dr. Russell Lloyd (formerly Chief, Branch of Range Studies, Bureau of Land Management) and Dr. N. K. Roberts, then chairman, Center for Social Science Research on Natural Resources, Utah State University. Early in April, 1963, the Bureau of Land Management formally requested the Director of the Utah Agricultural Experiment Station to explore the possibility of developing and conducting a project leading to better management of pinyon-juniper woodlands. Five objectives were originally spelled out by the Bureau of Land Management: (a) to develop ecological criteria for classification of pinyon-juniper sites; (b) to develop the minimum essential ecological data needed for management under various alternatives; (c) to clearly identify the multiple products of woodland ranges and to determine the competitive - complementary - supplementary relationships among them; (d) to assess economic value of the multiple products; and (e) to make an economic analysis of the various management alternatives and woodland uses on the major sites. A memorandum of understanding was signed in the middle of June, 1963 and a project work plan, drawn up by Dr. Roberts and Dr. T. W. Daniel, (Forest Science Department, Utah State University) was adopted later that summer. Dr. Roberts was the over-all project coordinator; Dr. Daniel was the ecological phase leader; in December 1964, Dr. A. LeBaron was made economics phase leader.

This volume reports on objectives a, b and part of c. It is hoped that they have been attained. In any event there can be little doubt about the general results that can be expected from reliance upon cross-sectional data in any future pinyon-juniper studies; absence of experimental controls makes data interpretation extremely difficult. Nevertheless, a number of interesting and worthwhile relationships have been developed, many of which should have direct application in management practices.

Authors of the various sections in this volume are indicated in the appropriate sub-headings. The contribution made to the successful completion of this project by the three Bureau of Land Management personnel assigned, E. Eberhard, H. E. Isaacson, and R. J. Rivers, is evident from their written work. References are to listings following each section.

In addition to the two volumes comprising the project report, attention is directed to the research report submitted by W. Meiners (assigned by the Bureau of Land Management to the ecological team during the first portion of the study) submitted in partial fulfillment of the requirements for a Master's Degree granted Utah State University, June 1965, entitled: "Some Geologic and Edaphic Characteristics Useful to Management Programming Within the Pinyon-Juniper Type". Except for Section 1 and Section 4 (parts A and B) the entire contents of this volume were edited by Dr. Allen LeBaron.

Office records obtained by the economics group from various land management agencies are linked to control sites visited (Section 7) but there may be inaccuracies both as to project identification and treatment practice. In some instances the apparent treatment was at variance with office records: areas supposedly seeded were barren of introduced species, machinery appeared to have been used in areas reported as hand-chopped, what were clearly tree control areas were identified by agency personnel as spraying projects, etc. All ecological plots are thought to have been located accurately to the quarter-section, but difficulty was still encountered in determining specific projects visited.

It may seem that there are anomalies in the numbers of plot locations reported in the various sections to follow. Actually this is not the case. In most instances tree, soil, and understory vegetation data were collected from every plot. But sometimes circumstances dictated the need for only soil and forage data or for certain tree measurements. Thus, while something like 430 separate sites were visited, only slightly over 400 tree or soil plots are reported; information was obtained from about 390 grass plots. The frontispiece is a map illustrating the approximate locations where ecological data were gathered during the course of this study. Many of these locations are on or adjacent to pinyon-juniper control and reseeding sites, but unfortunately these cases cannot be illustrated on such small scale.

Dr. E. B. Wennergren, Director
Economic Research Institute
Utah State University

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1. ECOLOGICAL PHASE ACKNOWLEDGEMENTS AND INTRODUCTION

T. W. Daniel, Ecology Phase Leader

The pinyon-juniper type covers an area of approximately 60,000,000 acres in western United States with the majority of the type occurring within the five state study area. Pinyon-juniper sites are the transition zones between the shrubs and grasslands at lower elevations and the commercial types or mountain browse type at higher elevations. Differences in rainfall and soil texture patterns account for the boundaries between the zones. The pinyon-juniper type is associated with a rainfall total of between 10-17 inches and at minimum rainfall occurs on coarse textured soils. The transitional pinyon-juniper has been neglected in an effort to answer problems or to exploit the resources of the more valuable cover types above and below it.

The Bureau of Land Management's awareness of the lack of information for the proper management of the pinyon-juniper type resulted in a request for a study investigating the economic and ecologic factors involved in evaluating various management alternatives. Keith Roberts, in collaboration with T. W. Daniel drew up the requested project proposal. It was accepted and financed by the Bureau as a cooperative project with the Utah State University Agricultural Experiment Station. In addition to a grant to the Experiment Station, three Bureau personnel were assigned to the ecology team for a period of three years.

A project as broadly based and fundamental as a study of the pinyon-juniper type was of interest to all the land management agencies within the study area. These agencies contributed advice and data on which the field work was initiated. The Bureau of Land Management was actively represented in the planning by R. D. Lloyd, Edwin Zzidlicz, Myrvin E. Noble, Archie D.

Crafts, R. D. Nielsen, and H. E. Jones as well as by the BLM men assigned to the study. The Forest Service contributed through Joel Frykman, C. A. Wellner, O. C. Olson, A. P. Caporaso, S. S. Hutchings and D. E. Parker. A considerable body of data as well as advice was obtained from C. T. Prout Jr., K. Hugie, E. Olsen, Lamar Mason and Erasmus Williams of the Soil Conservation Service. Several staff members of Utah State University assisted the ecological work through advice, laboratory facilities, and statistical procedures and analysis. The major University contributors were C. W. Cook, Rex Hurst, R. W. Miller, J. P. Thorne, N. E. West, and R. R. Moore. District Managers and their personnel of the BLM were helpful in advancing the aims of the project with their contributions of time and materials, and in response to emergency situations. Phillip Solenberger and W. E. Meiners were initially assigned to the project and contributed to its successful conclusion. The Forest Science Department students, whose assistance in the field work during the summer months was very important, were Gerhard Glatzel, G. A. Landrum, and Philip Unterschuetz the first summer, and T. R. Meyer and W. K. Rother the second summer. Richard Marasco and Terrance Glover, graduate assistants in the Department of Agricultural Economics, helped perform statistical analysis of part of the ecological data.

In an effort to exploit the experience and advice of the various government agencies actively involved in the management of the pinyon-juniper type, two meetings were called at which representatives of the Bureau of Land Management, U. S. Forest Service, Soil Conservation Service and the U. S. U. Agricultural Experiment Station pooled their ideas as to the size of the region to be covered in the limited time, types of data to be collected, and the methods to be used for the collection of the data. The first meeting was in Salt Lake City on August 22, 1963, and the consensus was that the study should be an extensive survey covering the Colorado Plateaus and the

Basin and Range provinces as far south as the Mogollon Rim, Arizona and Soccoro, New Mexico. It was decided that the pinyon-juniper type was more in need of a set of standards that could be applied throughout the region than an intensive survey of a limited area. The second meeting was a two day field trip (September 3 and 4) in the vicinity of Monticello, Utah. Twenty-three men from several land management agencies gathered to discuss field procedures and the problems inherent in trying to get, with a limited sample, an adequate representation of the variations in the type. As the result of these meetings, a considerable body of heterogeneous plot data was gathered from various agencies with the Soil Conservation Service as the predominant source. These data were summarized, and, on the basis of the results, Robert Rivers drew up a questionnaire for submission to all the BLM District Managers in the region. This questionnaire requested the location and description of pinyon-juniper sites of poor, medium and high quality. After receiving the information from the District Managers, Rivers visited every district in order to select sample sites which conformed to the needs of the study. In June, the full ecologic team including three forestry students began the plot measurements. In the course of the field season they visited every BLM district within the study area.

In the first year, the field work concentrated on the tree plots and took advantage of burns and eradication sites when suitable tree plots could be located in their vicinity. No special effort was made to locate eradications but rather to visit the cross-section of tree-sites selected in the spring. This procedure allowed the economic team a field season for selecting the eradication sites on which the ecologic team was to collect data on the grass production, tree height-diameter curves and soil profile characteristics in the second field season. In the second field season the ecologic team supplemented the tree-plot data of the previous year in order to increase the number of eradications visited at various locations. For the most part, tree plots were established along the margin of an eradication. These tree plots provided additional tree-plot data as well as aided in determining the site index of the eradication.

In the winter of 1964-65, the first year's data were analyzed so as to modify field procedures the second year. In the second field season, the early season work was a continuation of the emphasis on tree-plot data collection. Later when grass production had reached a peak on areas with the spring developer species, the emphasis shifted to collecting grass production data on pinyon-juniper eradication and grass seeding projects. During the winter of 1965-66, the data were analyzed for presentation in this report. The ecological conclusions are presented in compartmented units by the individuals who had primary responsibility for the collection and analysis of the data reported.

2. FIELD METHODS

2.a. Forest Data--R. J. Rivers

A total of 405 pinyon-juniper sites were evaluated during the 1964-1965 field seasons. These sites were located throughout the five southwestern states to facilitate determination of the ecological relationships of four major woodland species: Pinus edulis, Pinus monophylla, Juniperus osteosperma and Juniperus monosperma. Some of the areas sampled supported Juniperus scopulorum and Juniperus dippeana, and, although these trees were measured, their ecological relationships were not studied. During the 1964 field season major emphasis was on woodland site evaluation; during the 1965 season emphasis was placed on tree control/reseeded sites and their adjacent woodland stands.

The main criterion for tree plot location was the existence of a mature/over-mature dominant pinyon or juniper tree. This tree was called the "site tree." The site tree was selected because: (1) it was the tallest tree on the particular site; (2) it was relatively free of stem defects (such as excessive branching); (3) it was located where it would not be susceptible to any abnormal site factors (such as proximity to a water course). An attempt was made to locate such site trees throughout the various range, soil, and geologic provinces associated with the P-J type. Although the tree plots established during the 1965 field season were located adjacent to tree control projects, emphasis was still placed on locating a mature, dominant tree to serve as a "site tree."

Having selected a site tree, a tenth (1/10) acre rectangular plot was established. The plot dimensions were 100' x 43.6'. The site tree was used to reference the uphill side and short axis of the plot center. Woodland data obtained from each study site included: (a) fixed plot data; (b) variable plot data.

Fixed plot data- The following list illustrates the type of data collected for each tree on the fixed plot during each field season:

	1964	1965
Diameter at 1'	X	X
Diameter at 4 1/2"	X	X
Tree height	X	No
Crown diameter	X	No
Crown height	X	No
No. of trees 1"-4 1/2"	X	X
No. of trees less than 1'	X	X
Comments on tree vigor and form class	X	No

Variable plot data- On each site a number of trees, not necessarily located on the fixed plot, running the gamut of various diameter classes, were measured. These were specially selected to avoid multiple stems, deformed, suppressed, or rotted and broken trees. These measurements were used to construct height/diameter site curves.

Disks from the site tree and several other trees in this group were collected at 1' diameter to provide enough basic data for height-age and diameter-age relationships.

In addition to forest resources data, many "eradication" plots were established in 1965. These 10th acre plots provided information on tree kill, growth rates, and slash cover (Sections 6 and 9).

2.b. Range Data--H. E. Isaacson.

Since the main objective of the ecological study was to develop criteria for classification of pinyon-juniper sites and to establish a basis for recognition of these sites, all measurements during the 1964 field season were directed toward that end. The second field season (1965) differed; emphasis was placed upon collection of vegetational production data from woodland conversion projects in an attempt to discover if tree classification may be correlated to success or failure of such projects.

Vegetational measurements included: (1) foliage cover of both the tree layer and understory vegetational layer; (2) species composition of the tree canopy and understory; (3) annual production of understory vegetation. The additional measurements made the second year on woodland conversion projects were: (1) understory production on both treated and non-treated area; (2) basal area of grass on both treated and untreated areas.

The basic sampling procedures for the 1964 field season was as follows:

Tree canopy and species composition were measured along three 100 foot transects at intervals of 1 foot. The initial transect was located parallel to the contour, with the 50 foot mark spaced 15 feet down-slope from the site tree. The succeeding transects were perpendicular to the proceeding one in the form of a U around the site tree.

A spherical densiometer [Lemmon, 1956] was leveled at each foot along the tape and species hits were recorded if tree cover was sighted at the center crossmarks of the instrument.[1] This information was used to compute species composition of the total tree canopy. If species were not encountered, but trees were present in a tenth-acre plot positioned along the first 100 foot transect [Sec. 2.a], they were marked P (present).

---

[1] The instrument was not used in accordance with the instructions for measuring forest overstory, because of the uneven age and height of trees encountered in the individual stands and the magnitude of difference in mature tree height between stands (10 feet to 47 feet). It was the only instrument available that would offer a close measurement of woodland tree canopy over a specific point along a transect.

The percentage contribution made by each understory species to total understory composition was obtained by ocular estimate. The percentage estimates were made within a circular plot (approximately 3/4 acre) formed by a 100 foot radius from the site tree. The lower vegetation layer was generally so sparse that a large area had to be covered to find diversification in species. This was especially true where tree canopy exceeded 30 percent. Trace species were also recorded where species were not outside the plot.

At 25 foot intervals along each transect, circular 9.6 square-foot plots were spaced, and annual production of grass, forbs, browse and annuals was estimated by the forage weight-estimate method Frischknecht and Plummer, 1949; Perchanec and Pickford, 1937 . Ten percent of these latter estimates were randomly selected and checked in the field for green weight and dried for conversion of green weight to air-dry weights.

Whenever tree plots were adjacent to control projects, additional grass production was measured on 20, 9.6 square-foot plots spaced at 25 foot intervals along two parallel transects. These transects were established on homogeneous sites in conversion areas and 20 comparison plots exhibiting similar site conditions were spaced within the untreated areas. Where untreated areas were small and did not afford such a large sample, 10 plots were used (this was necessary only on projects located on Indian reservations in Arizona). Estimates of grass basal area as a percent of each 9.6 square-foot plot were made. Also the percent of each plot taken up by usable or ungrazable area (debris, fallen trees, rocks, etc.) was estimated.

Climatic data from records of Weather Bureau stations located within or close to the pinyon-juniper type were summarized. Physiographic and recent geologic historical information was gathered for the regions studied.

2.c. Soil and Site Data--E. J. Eberhard

During the field seasons of 1964 and 1965, soil and site information was collected from 403 plots within the pinyon-juniper type in Utah, Nevada, western Colorado, northwest New Mexico, and northern Arizona. Soil profile pits were located within tree stands on 351 of these plots, and the remaining 52 pits were located on tree control projects.

Since major emphasis during the 1965 field season was on analysis of grass production following tree control, tree plots were located adjacent to control projects whenever possible. An effort was made to select tree and adjacent project plots which were comparable in measured soil and site factors. If soil conditions on the project site were different from those found on the tree plot, a complete soil profile description was made for the project site. In cases where soil and site conditions appeared essentially the same, either an abbreviated soil profile description of the project site was made, or the sites were treated as being identical.

The general guide used in measuring various soil and site factors was the Soil Survey Manual [United States Department of Agriculture, 1951].

Soil pit location- On tree sites the soil pit was located down-slope, and usually about five feet from the base of the site tree. Care was taken to avoid areas where run-off water might accumulate or where recent soil deposition or removal had taken place. The face of the pit was located where it was subject to site tree crown influence. Soil pits located on project sites were dug in the areas from which grass production measurements were obtained. Areas where run-off water might accumulate or where recent soil deposition or removal had taken place were avoided. Prior to digging any soil pits, several auger holes were drilled to insure the selection of a representative soil profile for the site.

Soil pit depth- Each soil pit was dug by hand to a depth of 5 feet or until bedrock conditions made further digging impossible. For the abbreviated profile descriptions on project sites, the pit was dug to a depth of 18 inches and then a soil auger was used to compare the similarity between the balance of the profile and the previously described profile in the adjacent tree stand.

Slope gradient- Slope was measured in percent with an Abney hand level.

Aspect- Slope aspect was measured with a hand compass to the nearest bearing or azimuth degree.

Slope character- Slope character was classified as being uniform, undulating, concave, convex, or complex.

Slope position- Slope position of every plot was classified as being on either a waxing slope, a waning slope, a free face, or a constant slope.

Slope deposition- After a soil pit was completed, the slope deposition was recorded as being material from transported, residual, or colluvial origin.

Parent material- From field observations and available geologic maps, the parent material (or parent materials) of each profile was identified by one of the following classifications: (1) Sand, (2) Loess, (3) Fine alluvium, (4) Coarse alluvium, (5) Tertiary sediments, (6) Lacustrine deposits, (7) Sandstone, (8) Shale, (9) Limestone/dolomite, (10) Acid igneous, (11) Basic igneous, (12) Metamorphic rock, (13) Undifferentiated materials.

Soil permeability- An estimate of relative soil permeability was made through a consideration of structure, texture, porosity and cracking within each profile. Permeability was rated as very rapid, rapid, moderate, or slow.

Depth and thickness of horizons- Once horizons were identified, the depth and thickness of each horizon in a profile were measured and recorded to the nearest one-half inch.

Horizon designation- In accordance with procedures outlined in the Soil Survey Manual, an attempt was made, in the field, to give each horizon its appropriate symbol designation. Since this designation was not checked by laboratory measurements, the accuracy achieved may be questioned.

Color- Dry and moist color of the soil in each horizon was determined by using the standard color names, and the Munsell notation of color.

Texture- Soil texture was determined by the "feel" method. Samples of known texture were checked periodically throughout the field season in an effort to maintain a consistent basis for textural classification.

Structure- An estimate of the structural condition of each horizon was made by referring to standard soil structural forms, size of forms, and relative strength of these structural forms.

Consistence- Both dry and moist consistence of soil in each horizon were estimated using rating systems found in the Soil Survey Manual.

Stickiness and plasticity- These soil physical factors were measured using soil samples containing water slightly in excess of field moisture capacity. Rating systems in the Soil Survey Manual were used in making the recorded estimates.

Horizon boundaries- Boundaries between horizons were described in terms of distinctness and topography as specified in the Soil Survey Manual.

Rockiness or stoniness- A percentage estimate of the volume of each horizon occupied by rocks or stones was made. Gravel was not included in this estimate, but was considered in the textural classification.

pH- The pH of each horizon was determined using the standard indicator solutions of phenol red, creosol red, and thymol blue with the color chart of indicators from Clark [1928].

Lime or calcium carbonate- The relative amount of lime in each horizon was determined by the reaction of the soil with a 10% HCL solution. Horizons were rated none, weak, moderate, strong, and very strong in lime concentration. The degree of lime cementation in a horizon was rated as being weak, moderate, strong, or indurated.

Moisture holding capacity- The total potential moisture holding capacity of each profile was estimated in the field by considering soil texture, rockiness, and profile depth. Ratings of very high, high, moderate, low, or very low were assigned to each soil profile.

Roots- The size, relative abundance, and distribution of tree and grass roots encountered in the profile were recorded. An attempt was made to determine if tree roots occupied fractures in bedrock.

Location and elevation- The topographic maps printed by the U. S. Geological Survey and prepared by the Army Map Service were used to locate all plots for future reference. These maps, which have a scale of 1:250,000 and a contour interval of 200 feet, were the most up-to-date available for a majority of the study area. Plots were located by township, range, section, and quarter section, where possible. Elevation was recorded to the nearest 100 feet.

Collection of soil samples- Approximately one pound of soil for each horizon was collected in plastic bags for later laboratory analysis. From the abbreviated soil pits on the tree control project, only samples of the A1 horizon and the B or AC horizon were collected.

Photographs- A photograph showing the site tree and surrounding trees and vegetation was taken on each tree plot. A photograph of each tree removal project was also taken. In project photographs, the view-finder was focused on a spot 20 feet from the camera lens to provide some basis for later comparison of grass stands.

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3. DESCRIPTION OF ECOLOGICAL PROVINCES WITHIN THE STUDY AREA

H. E. Isaacson

The study area consisted of portions of five western states: Utah, Nevada, Arizona, New Mexico, and Colorado. This section describes an attempt to subdivide the area into provinces on the basis of ecological similarities. Data are separately analyzed from three tentative provinces demarcated according to the methods and rationale of Franklin [1965]. The provinces are outlined on the map shown as Figure 3.b.1 and are titled Escalante-Sevier, La Sal, and Coronado, respectively.

3.a. Literature Review

Pinyon-juniper woodland commonly occupies elevations of 5,000 to 8,000 feet in all five states. It is generally accepted that the lower limit of the woodland type is restricted by deficient moisture [Pearson, 1931] or finer valley soils [Woodbury, 1947; Meiners, 1965]. Junipers appear to be invading sagebrush and grass types adjacent to the lower altitudinal limit. This may be the result of decreased fires and increased grazing [Stoddart and Smith, 1955]. The upper edge of the woodland belt grades sharply into either Ponderosa pine (Arizona and parts of Colorado and New Mexico) or a mountain browse zone (Colorado, Utah, and Nevada). The ecotone is almost always narrow, 200-300 linear feet [Woodbury, 1947; Rasmussen, 1941; and Merkle, 1952]. At the upper altitudinal limit, Pinyon and Juniper are confined to the warmest parts of the topography [Phillips, 1909; Pearson, 1931; Rasmussen, 1941; Daubenmire, 1943; and Richmond, 1962].

Junipers appear to establish first on all the recently invaded sites. Old Juniper trees in a mixed stand still have the characteristic shape of open-stand trees. Woodbury [1947] notes evidence in plots located on the Arizona Black Mesa that pinyons have a tendency to follow junipers in the invasion of new areas. This succession seldom follows to the lower altitudinal limits of the usual juniper codominant.

Woodbury [1947] emphasizes that distribution limits at either the upper or lower edges or at the discontinuities within the pinyon-juniper woodland at given locations are not necessarily set by climate alone but by the interaction of all agencies involved, climate, soil, soil moisture, and biota. The general locations may fit the climatic pattern, but the details of the limits result from the interactions of many factors.

These factors do not remain constant over such a broad expense as is covered in this study. A variety of habitats result from different environmental conditions. In the Pacific Northwest, Franklin [1965] divided the true fir-hemlock forest into managable units based upon geologic, topographic, climatic, edaphic and vegetational characteristics. He considered the units ecological provinces because of the several factors used for regional breakdown. This appeared to be a useful approach in establishing divisions in the pinyon-juniper study area.

3.b. Description of the Area

Sampling was limited to the Great Basin and the Colorado Plateau physiographic provinces [Fenneman, 1931]. This encompasses a portion of the five states already mentioned. Pinyon-juniper woodlands occupy extensive areas at middle elevations in the study area. These woodlands occur in areas with widely divergent geologic histories, topography, and climatic conditions. Within the sampling area, there is also considerable variation in botanical composition both for trees and understory. Thus, there is a need to subdivide this vast woodland area into ecologically consistent units. The ecological province boundaries drawn in Figure 3.b.1 are confined to the heart of the pinyon-juniper type in

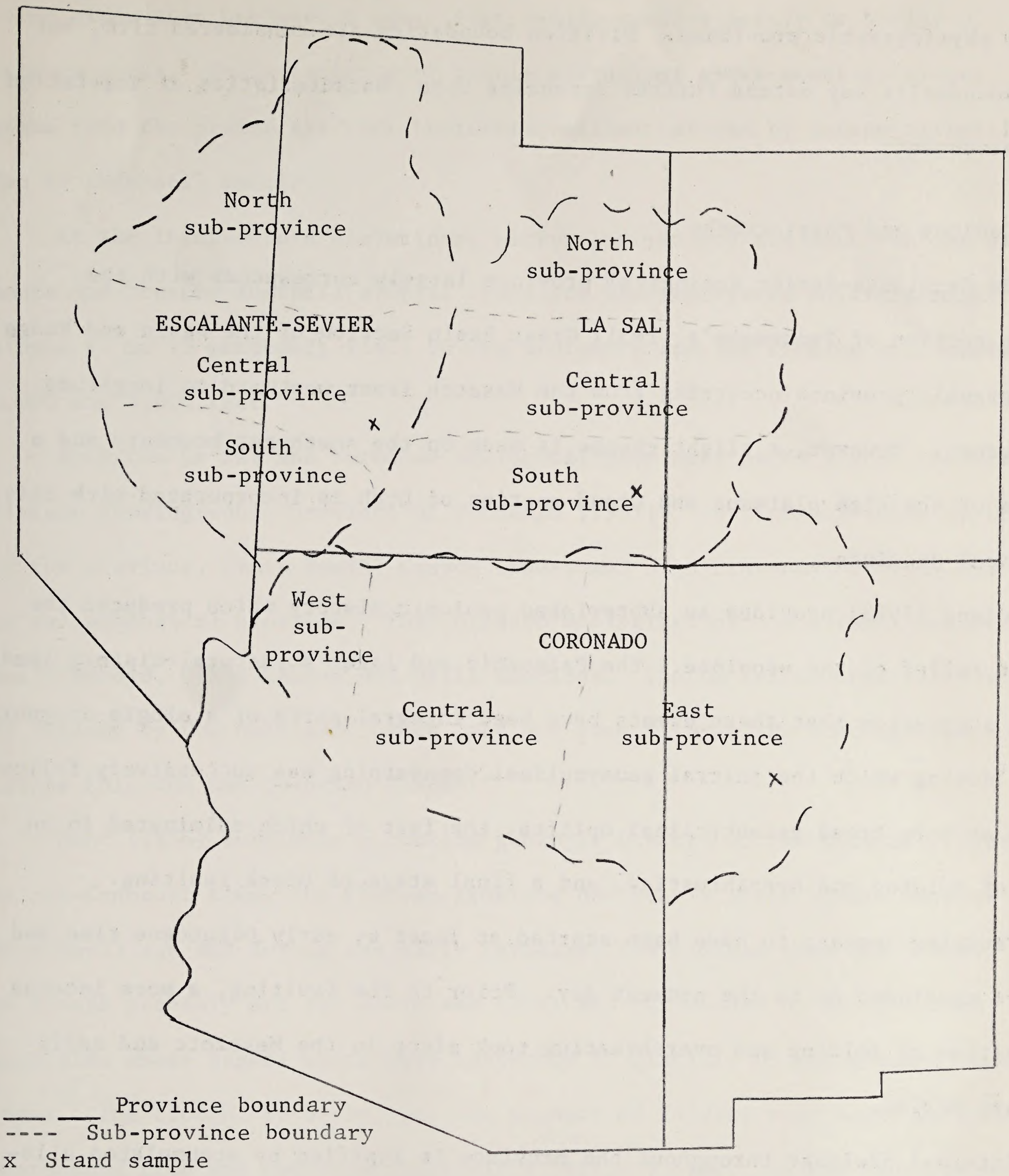
North sub-province
ESCALANTE-SEVIER
Central sub-province
South sub-province
North sub-province
LA SAL
Central sub-province
South sub-province
West sub-province
CORONADO
Central sub-province
East sub-province
x
x
x
Province boundary
---- Sub-province boundary
x Stand sample

Figure 3.b.1. Boundaries of provinces based on vegetation composition alone.

the two physiographic provinces. Division boundaries are considered firm, but outer boundaries may extend further depending upon characteristics of vegetation and environment.

3.c. Geology and Physiography

The Escalante-Sevier ecological province largely corresponds with the eastern portion of Fennemann's [1931] Great Basin Section of the Basin and Range Physiographic province occurring from the Wasatch front westward to longitude 115 degrees. However, a slight change is made on the southeast boundary and a portion of the high plateaus and Grand section of Utah is incorporated with this ecological province.

Noland [1943] provides an abbreviated geologic history which produced the present relief of the province. The Paleozoic and later structural history leads to the suggestion that these events have been integral parts of a single orogenic cycle, during which the initial geosynclinal downwarping was successively followed by one or more broad geoanticlinal uplifts, the last of which culminated in an epoch of folding and overthrusting, and a final stage of block faulting.

Faulting appears to have been started at least by early Oligocene time and to have continued up to the present day. Prior to the faulting, a more intense deformation of folding and overthrusting took place in the Mesozoic and early Tertiary period.

Internal drainage throughout the province is typified by accumulated alluvium in low valleys brought down from mountains altered by erosion. The topography consists of isolated mountain ranges (largely fault block mountains) separated by aggraded desert plains. Valley deposits are often very deep and are generally unconsolidated. The ranges are commonly parallel in a general north-south orientation and extend to 50 and 75 miles in length. According to Fenneman [1931] the rocks which compose the mountains are largely sedimentary, being older than Cretaceous age. Some ranges consist partly or wholly of igneous rocks. Characteristic of middle elevations where mountain slopes grade into the plains are rock pediments, either covered by a deep alluvial fan or thin soil mantle.

At the intermediate elevations, pinyon and juniper are found on the pediments and steeper foothill slopes. Sampling was restricted to the gentle slopes (2 to 15 percent); i.e., to the pediments and low sloping hills between 5,000 and 8,000 feet.

Both the La Sal and Coronado ecological provinces occur within the Colorado Plateau physiographic province of Fenneman [1931]. Portions of three sections of the province, Uinta Basin, Canyon Lands, and High Plateaus of Utah, form the La Sal ecological province. The Coronado ecological province comprises Fenneman's Navajo, Grand Canyon and Datil sections. The La Sal ecological province is drained by the Colorado, Green, and San Juan Rivers, the Coronado by the Little Colorado and Colorado Rivers.

Hunt [1956] furnishes a concise geologic history of the Colorado Plateau. In pre-Cenozoic time, the Plateau province had been a shelf area. In pre-Cretaceous age and during the early Tertiary, the Plateau area was a basin or trough probably not far above sea level and surrounded by newly-formed mountains whose higher parts were subjected to glacial, or periglacial conditions. The trough, or basin, was the product of folding that began in late Cretaceous time and continued into early Tertiary time. In its lower parts, several thousand feet of lacustrine and fluviatile sediments were deposited. After Eocene time conditions changed markedly. Aggradation ceased and general degradation began; igneous activity, in the form of volcanism and intrusions, became extensive; there was extensive faulting, especially along the west and south edges of the Province; and epeirogenic uplift began. The erosion, igneous activity, faulting and uplift have continued to the present day.

Colorado Plateau deposits of early Cenozoic age are well represented on, or adjacent to, the Colorado Plateau; but deposits of late Cenozoic are are scarce, thus late Cenozoic geologic history is not too well known. In adjoining parts of the Basin and Range province the reverse is true; these deposits of early Tertiary age are scarce but deposits of late Tertiary age are extreme.

Present-day characteristics of the Colorado Plateau are described by Fenneman [1931].

The first distinguishing feature is approximate horizontality of its rocks. In the contiguous provinces the strata are folded. Tilted beds are limited to a few great monoclines and the borders of a few local uplifts. There is no lack of steep slopes but, except on recent volcanic features, they are due to erosion guided in some cases by structure.

The second distinguishing feature is great elevation. Aside from canyon bottoms, no considerable portion of it is lower than 5,000 feet. Between this and 11,000 feet, there are plateaus of all altitudes. Except where bordered by high mountains on the north and east, the plateau province is higher than surrounding areas, separated from it by bold escarpments.

Another feature which distinguishes the entire province is its remarkable canyons, not one but hundreds.

Physiographic differences between the two ecological provinces are based mainly on the degree of wastage. The La Sal province shows a higher or stronger relief from denudation processes; farther south in the Colorado province the plateaus are less deeply and minutely canyoned. Pinyon-juniper woodlands are found on plateaus, mesas, ridges and lower mountain slopes at elevations from 5,000 to 8,400 feet. Selected scenes from the various provinces are shown in Figures 3.c.1, 3.c.2, and 3.c.3.

3.d. Climate

According to a map of the moisture regions of the United States [Thornthwaite,

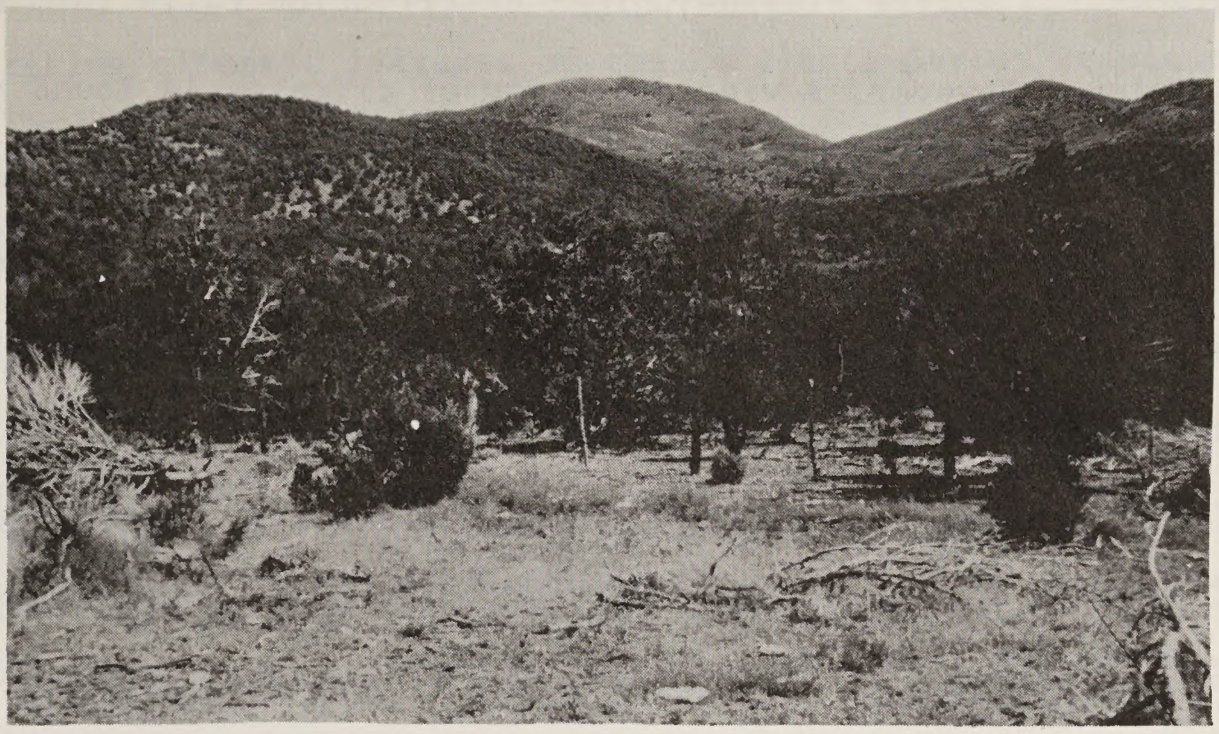
Figure 3.c.1.
View of Escalante-Sevier
Woodland

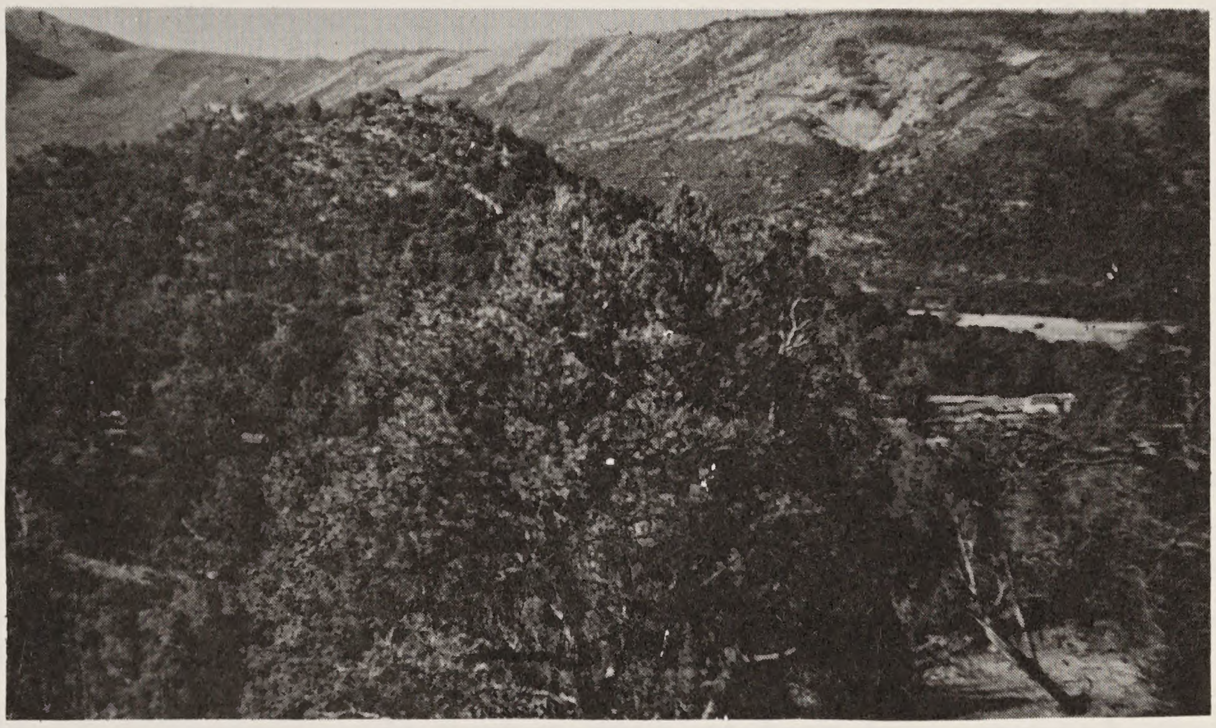
Figure 3.c.2.
View of La Sal Woodland

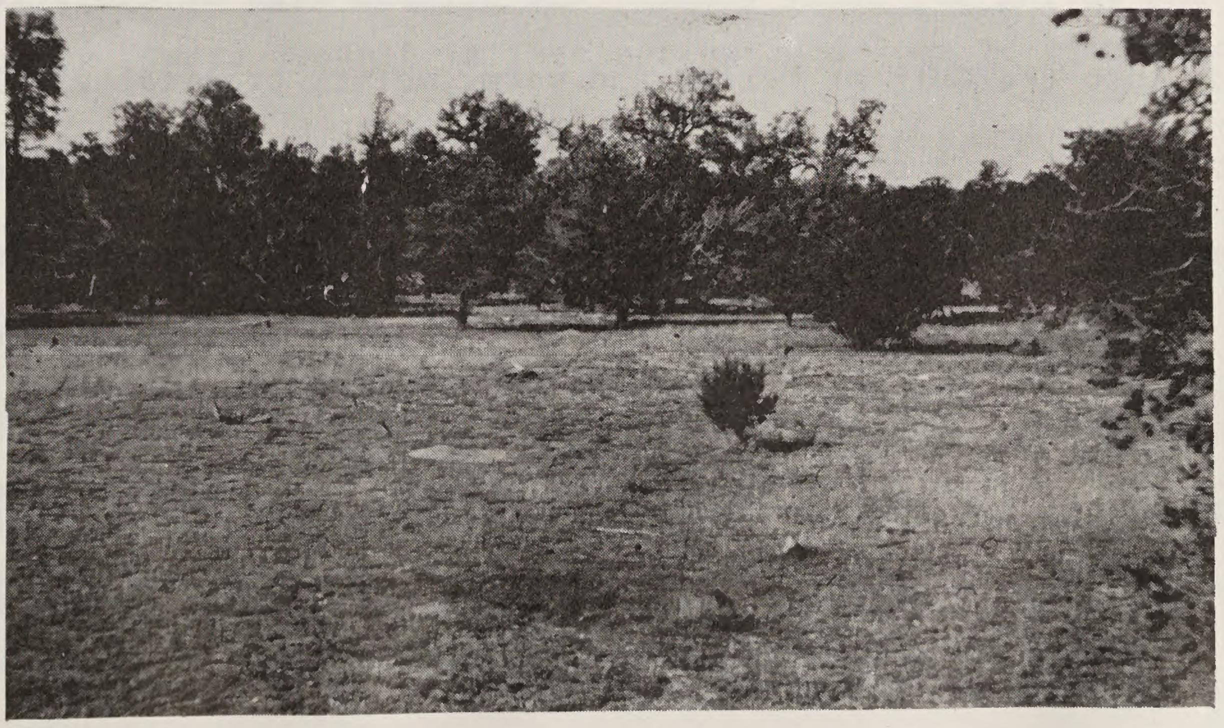
Figure 3.c.3.
View of Coronado Woodland

1931], almost the entire pinyon-juniper distribution falls into the semi-arid classification. However, a wide diversity of climates is found over the five state expanse. Four important factors which exert an influence on local climates are latitude, altitude, moisture sources, and orientation of mountain ranges.

Landsberg [1961] discloses how these factors effect climate in the study area. Seasonal weather changes over this region are largely the result of the seasonal migration of two large high-pressure centers: the "Pacific High" and the "Bermuda High." During the wintertime, the Pacific High is in its most southerly position and is relatively weak. This allows storms to swing around its northern edge and cross the west coast sometimes as far south as Lower California. During the same period the Bermuda High is weak and far out to sea and has little influence on cold season climate. Thus, winter storms track across Nevada, Utah and Colorado more frequently during October-March than over the two southern states. There is a diminishing effect as the storms pass over the western mountain ranges and high mountains of Utah. Although not as many cold-season storms track across Arizona and New Mexico, those that travel that far south do not have to cross the highest ranges of the Sierras.

In the spring the Pacific High strengthens and moves northward, storms become less frequent and tend to move across the country at higher latitudes. Late in the spring and early summer, the Bermuda High develops its westward extension into the Gulf of Mexico and warm, moist, tropical air from that source begins to move from a southeasterly direction across the Southwest. This flow gets weaker as it pushes west and less moisture is transported inland. Western Arizona and southwestern Utah receive considerably smaller amounts of moisture than their eastern sections and the more easterly states of New Mexico and Colorado. Nevada is too far west to receive significant gulf moisture, so its precipitation is very light during the warm season. During September the Pacific High and the Bermuda High begin to weaken. By fall, the Pacific Ocean is again the major storm source.

The most striking climatic features of the Escalante-Sevier Province are bright sunshine, widely divergent precipitation pattern between deserts and mountains (because of orientation of mountain ranges to normal storm track), dryness and purity of air, and large diurnal temperature ranges. Yearly precipitation fluctuations and fluctuations over longer cycles are usually of great magnitude.

The mountainous parts of the northern portion receive more precipitation, especially in winter and spring, than the southern mountain portions because they lie within the path most frequented by storms in that half of the year [Alter, 1955]. Monthly distribution of precipitation over most of the province shows June, July and August to be driest. Then there is a gradual increase reaching a maximum in March, April and May. Evaporation is moderately heavy because of the dry atmosphere and high-wind velocities.

The most distinctive aspect of the La Sal province climate is the comparative uniformity of the weather conditions from day to day. This is due to the high mountains which practically surround the section and which deflect the course of low-pressure areas [Sherrier, 1955]. A substantial part of the precipitation occurs in winter and early spring; the southern end of the province shows a higher peak at this time of year than the northern portion. There is a prominent tendency toward drought in late spring, and June is often extremely dry. Another important period of precipitation is in late summer during July and August with a tapering-off after October. Skies are generally sunny over the area throughout the year.

In the Coronado province precipitation occurs chiefly during two seasons. Maximums are reached during July, August and September (in the form of convection showers) and most of the rest is received in December through March. Normally May through June is extremely dry. The percentage of sunshine is very high throughout the year. The extreme western portion of the province is less affected by the flow of Gulf moisture and the summer precipitation peak is not as pronounced.

Woodin and Lindsey [1954] divided the pinyon-juniper type east of the continental divide primarily upon the basis of precipitation periods. They were considered more important than temperature as determinents of vegetation differences. Following [Smith, 1940], they used hythergraphs to show differences in the eastern slope subdivisions. Hytherographs for the three ecological provinces delineated in the present study support the divisions chosen (Figure 3.d.1).

In the Escalante-Sevier province, the maximum precipitation occurs in late winter and spring leaving the main growing season either dry or dependent upon unreliable short-duration showers. The La Sal province has a good seasonal distribution of precipitation and temperature during the growing season. Only May and June show less than an inch of precipitation during spring and summer but moisture accumulated in the soil from winter and spring storms assists vegetation through this period. Most striking is the Coronado hytherograph which shows the mid-summer peak of precipitation. Vegetation that requires substantial spring moisture cannot be introduced.

3.e Soils

There is great variation in soils supporting the woodland communities within each province; local variations occur because of differences in parent materials, topography, microclimate or time for pedogensis. The limited supply of moisture available for plant growth, weathering, and soil leaching is the chief controlling factor in the genesis and the resulting morphology of soils in the pinyon-juniper type. Low temperatures in the winter and spring, and summer drought further limit soil-forming processes for substantial portions of each year. Soluble salts are usually leached only to depths of 1 to 2 feet.

Though parent material differs greatly within short distances, certain generalizations can be made for the gentle sloping areas sampled in each province.

In the Escalante-Sevier province soils are derived from colluvium, alluvium

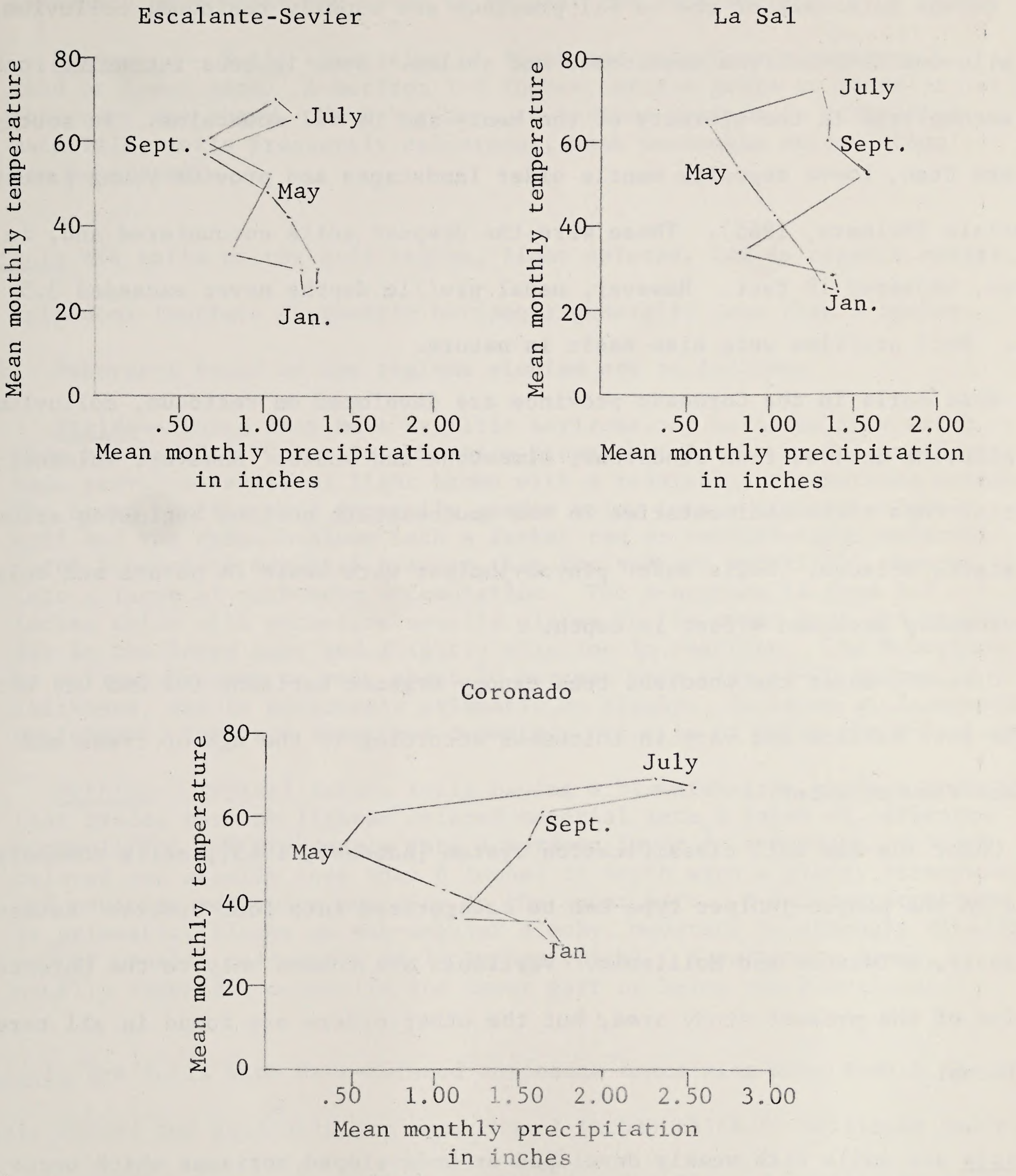

Figure 3.d 1. Mean monthly temperature plotted against average of the normal monthly precipitation for the three ecological provinces. Each point is an average of the monthly figures from several weather stations within one province.

and residuum of mainly sedimentary rock. Volcanic rock becomes important also in the southern half of the province. Soil depths seldom exceed 3.5 feet and the entire profile is basic in reaction.

Parent materials of the La Sal province are usually residuum, colluvium, and alluvium derived from sandstones and shales. Some igneous intrusive rock was encountered in the vicinity of the Henry and La Sal mountains. In southeastern Utah, loess deposits mantle older landscapes and provide young parent materials [Meiners, 1965]. These were the deepest soils encountered and, in places, exceeded 10 feet. However, usual profile depths never exceeded 3.5 feet. Soil profiles were also basic in nature.

Most soils in the Coronado province are developed on residuum, colluvium, and alluvium derived from sandstone, limestone and shale. However, volcanic material caps these sedimentaries in the southeastern portion beginning around Flagstaff, Arizona. Soils under pinyon-juniper were basic in nature and only occasionally exceeded 4 feet in depth.

Directly under the woodland tree canopy organic horizons (01 and 02) occur at the soil surface and vary in thickness according to the age of trees and surface flow of water.

Under the new soil classification system [Aandahl, 1965], soils commonly found in the pinyon-juniper type can be categorized into four Orders: Entisols, Vertisols, Aridisols and Mollisols. Vertisols are common only to the Coronado portion of the present study area, but the other orders are found in all three provinces.

Entisols are soils with weakly developed or undeveloped horizons which occur upon materials of recent age or where erosion and sedimentation are highly active; thus very little or no change has been made in the recently deposited parent material.[1]

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[1] Under the 1938 soil classification system, these categories would approximate the Alluvial, Lithosol, and Regosol great soil groups.

The two Suborders found in the pinyon-juniper woodland type are:

Orthents-- Skeletal soils formed on a recently deposited alluvium or imperfectly weathered rock fragment, A-horizon 1-18" where present, after which a stony or gravelly, frequently calcareous, platey, or granular structure may occur. No B-horizon. A weak horizon of calcium carbonate enrichment may occur at or near the rock surface.

Psamments-- Soils consisting of fresh and imperfectly weathered sand or loamy sand. A-horizon 1-8 inches, single grain or granular structure may occur. No B-horizon. C-horizon uniform or stratified materials, soils frequently calcareous, weak carbonate accumulation may be present.

Aridisols are soils of the arid region, light colored, low in organic matter, with epipedons (surface diagnostic horizons) generally less than 7 inches thick. Suborders found in the regions studied are as follows:

Argids-- Those that have argillic horizons, or horizons into which clay has moved.[1] Color is generally brown, but in the La Sal and Coronado provinces soils of light brown with a reddish cast sometimes occur. The brown surface soil generally grades below into a lighter colored soil and the reddish-brown into a darker red or reddish-brown material (with subsurface material heavier than the surface material), thence into a layer of carbonate accumulation. The A-horizon is from 2-7 inches thick with structure usually platey in the upper part and granular in the lower part and slightly alkaline in reaction. The B-horizon is yellowish-brown to red, about 20 percent more clay, 4-20 inches in thickness, and is moderately prismatic or blocky. Horizons of carbonate enrichment, that are sometimes cemented, occur in or below the B-horizon.

Orthids-- Typical desert soils having a brownish-gray surface horizon that grades through lighter colored material into a layer of carbonate accumulation and frequently into a hardpan layer.[2] A-horizon is light colored and usually less than 6 inches in depth with a platey structure, and exhibits vesicular porosity in the upper part. B-horizon structure is prismatic, blocky or sub-angular blocky, moderate to strongly alkaline and is usually calcareous (6-14 inches thick). A carbonate layer, usually cemented, occurs in the lower part or below the B-horizon.

Mollisols are soils with dark-colored epipedons containing more than 1 percent organic matter and generally are more than 7 inches thick.[3] Mollisols Suborder categorization is based upon climate. Suborder Xerolls and Ustolls would be found in the woodland type studied.

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[1] Brown or Reddish Brown great soil groups would approximate the Argids.

[2] The Sierozem great soil group would approximate the Orthids encountered.

[3] The Brown and Reddish Brown great soil groups also approximate several of these great groups.

Mollisols are generally brown at the surface but light browns with a reddish cast may be found in the La Sal and Coronado provinces. A-horizon is 7-20 inches, structure usually platey at the surface and granular in the lower part and slightly alkaline in reaction. B-horizon, where present, is lighter in color except where reddish brown at the surface. Reddish-browns grade into a darker red or reddish-brown material heavier than the surface horizon. The B-horizon may contain 20 percent more clay than the A-horizon. It is 4-20 inches deep, moderately prismatic or blocky. A carbonate enrichment horizon that is sometimes cemented occurs in or below the B-horizon.

Great groups encountered of the Suborder Xerolls (soils seasonably dry when not frozen) are Argixerolls (soils with an argillic horizon) and Haploxerolls (soils with a less altered B-horizon or a C-horizon below a mollic epipedon).

In the Suborder Ustolls (dry climates, usually hot in the summer) great groups encountered are Argustolls, soils with an argillic horizon; Calcustolls, soils with a calcic horizon but on Argillic horizon and Haplustolls, soils with a mollic epipedon on a C-horizon or less altered horizon.

Vertisols are soils formed on basalt lava and basalt cinders that cap sedimentary rocks.[1] The Suborder, Usterts, contains Vertisols associated with dry climate and hot summers.

> Usterts-- Dark colored A-horizon that varies in thickness (20 to 50 inches). The surface 1 to 4 inches has strong granular structure, but below this the horizon may have prismatic or weak to strong blocky structure with a slightly alkaline reaction. There is no B-horizon. C-horizon is massive with a large lenticular pattern of cracks when dry. Wide vertical cracks commonly extend from the soil surface into the C-horizon. These are 1 to 25 cm (1/2 to 10 inches) wide for at least half the depth of the solum. These soils are dominated by montmorillonite clay (over 35% clay).

In table 3.e.1 the many soils sampled during the course of the present study have classified according to the above system.

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[1] This category approximates the grumusols of the older classification systems.

Table 3.e.1. Percent of soil observations as classified in the new soil classification system

Entisols		Aridisols		Mollisols	Vertisols	No. of observations	Province
Ortherts	Psamments	Argids	Orthids				
24%	2%	24%	31%	19%	0	119	Escalante-Sevier
28%	9%	41%	8%	14%	0	139	La Sal
27%	3%	46%	8%	10%	6%	124	Coronado

When the total observations are summed, it is observed that the quantity falling in each order is about the same in every province. Thus, for the purposes of this report, it is concluded that soils provide the weakest element in demarcating pinyon-juniper ecological provinces.

3.f. Vegetation[1]

Sampling was restricted to areas supporting Pinus edulis, Pinus monophylla, Juniperus osteosperma, or Juniperus monosperma; however, Juniperus scopulorm and Juniperus deppeana were minor species in some communities. Where Gambel oak (Quercus gambelii) was encountered, it was never of sufficient height to be part of the tree canopy so it was considered an understory species.

Pinyon-juniper woodlands of the Escalante-Sevier province have a more uniform composition that those of the La Sal or Coronado provinces (Table 3.f.1). Utah juniper (Juniperus osteosperma) is the only juniper encountered at all elevations sampled. However, single leaf pinyon (Pinus monophylla) extends sporadically throughout the province. In the southeast portion of the province, Colorado pinyon (Pinus edulis) may dominate or be a minor species of woodland communities; where these two pine species interfuse, individual trees may have both single and double leaves.

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[1] Nomenclature for trees, shrubs and forbs follows Harrington [1964]; nomenclature for grass follows Hitchcock [1950].

In the restricted sampling area, the upper elevational range of the trees in this province was never visited. Data were collected on benchlands and low rolling hills. These areas grade sharply into steep hillsides also vegetated by pinyon and juniper trees. Since sampling was confined to the lower slopes, the elevation range was generally between 5,500 and 7,000 feet. The lower woodland boundary usually grades into a sagebrush-grass type.

Important understory species vary with both elevation and latitude. Common plants found throughout the province are big sagebrush (*Artemisia tridentata*), black sagebrush (Artemisia tridentata nova), and chicken sage (Artemisia tridentata arbuscula). The latter two species occur on ridges and slopes whereas big sage grows on deeper soils. Small rabbit brush (*Chrysothamnus viscidiflorus*), bitter brush (*Purshia tridentata*), squirreltail (*Sitanion hystrix*), Sandberg bluegrass (*Poa secunda*), bluebunch wheatgrass (*Agropyron spicatum*), Indian ricegrass (*Oryzopsis hymenoides*), Nevada bluegrass (*Poa nevadensis*), needle and thread grass (*Stipa comata*), white borage (*Cryptantha* spp.) and *Phlox* spp. are other common understory species.

Table 3.f.1 shows how certain species are related to latitudinal changes. Sites were grouped into three sub-provinces.

Of the species found in the south sub-province, galleta grass (*Hilaria jamesii*) and buckbrush (*Ceanothus greggii*) are probably the only species not found in northern latitudes. Cliffrose (*Cowania stansburiana*) appears to be important only in the south half of the Escalante-Sevier province.

Several of the plants relegated to the central sub-province are species that join the general woodland community listed above at higher elevations; the specific elevation would change as the latitudinal location changes. They are serviceberry (*Amelanchier alnifolia*), snowberry (*Symphoricarpos longiflorus*), mountain mahogany (*Cercocarpus ledifolius*), and Idaho fescue (*Festuca idahoensis*).

All of these species except mountain mahogany were probably more widely distributed before the lands become subject to heavy livestock and game concentrations. Mountain mahogany is generally found at higher elevations than the pinyon-juniper belt in the southern sub-unit.

Species that appear to be more common in the north sub-unit are balsam root (Balsamorhiza sagitata), Phlox longifolia and larkspur (Delphium spp.).

Woodland stands of the La Sal province are dominated by Colorado pinyon (Pinus edulis) and Utah juniper (Juniperus osteosperma). Single leaf pinyon (Pinus monophylla) has been reported in the area [Daubenmire, 1943]; however, it happened that none was encountered during the course of the present study. Rocky Mountain juniper (Juniperus scopulorum) may be a minor species at the upper elevational range. More often the pinyon-juniper belt grades into a mountain brush type at the upper elevational limits but may grade into a ponderosa pine (Pinus ponderosa) or Douglas fir (Pseudotsuga menziesii) type.

Several of the species universally found in the Escalante-Sevier province play the same role in this province. They are big sagebrush, chicken sage, little rabbitbrush, bitter brush, Indian ricegrass, Squirreltail and white borage. Additional species that characterize the province are mutton grass (Poa fendleriana), blue grama grass (Bouteloua gracilis), dry land carex (Carex spp.) and snake weed (Gutierrezia sarothrae). Beginning at medial elevations and extending to the upper range in the woodland belt, birchleaf mahogany (Cercocarpus montanus), serviceberry (Amelanchier alnifolia), gambel oak (Quercus gambelii), June grass (Koeleria cristata), and goldenrod (Solidago spp.) become important species also.

Table 3.f.2 indicates how species are restricted in latitudinally divided sub-provinces. For example, galleta grass (Hilaria jamessii) is common to more southern latitudes in both the Escalante-Sevier and the La Sal provinces. Three awned grass (Aristida spp.) is also more common in the south and central portion of the La Sal province at low elevations. Arizona fescue (*Festuca arizonica*) is found occasionally at mid and high elevations.

Several species, notably western wheatgrass (*Agropyron smithii*), Sandberg bluegrass (*Poa secunda*), *Phlox* spp. and *Aster* spp. were more often found in the central and north sub-provinces. Also in the central and north sub-provinces on better sites (higher elevations) were found bluebunch wheatgrass (*Agropyron spicatum*), beardless wheatgrass (*Agropyron inerme*) and snowberry (*Symphoricarpos* spp.).

In the Coronado province, Colorado pinyon (*Pinus edulis*) and Utah juniper (*Juniperus osteosperma*) are the main dominants. Single leaf pinyon (*Pinus monophylla*) occurs with Colorado pinyon in northwestern Arizona but is usually a minor species. In the southeastern portion of the province, one seeded juniper (*Juniperus monosperma*) may be present with *Pinus edulis* or may grow in pure stands. Rocky Mountain juniper (*Juniperus scopulorum*) may be present in small quantities throughout the province on favorable sites. The lower woodland ecotone consistently grades into a grass type while the upper ecotone grades into ponderosa pine (*Pinus ponderosa*). This province produces the largest trees of both pinyon and juniper. This is probably due to the distribution of precipitation, for the greatest portion falls during the growing season (Figure 3.d.1). Colorado pinyon trees 40-45 feet tall were measured on sites east of Farmington, New Mexico, and in Arizona. Juniper trees also grew to 35 feet on some of the best sites. The tallest pinyons (47 feet) were recorded on the south rim of the Grand Canyon where timber and woodland communities converge.

In this province, the understory is dominated by grass. Blue grama is most common and at many sites accounted for 40 or more percent of the understory composition (Table 3.f.3). Other important grasses are squirreltail (*Sitanion hystrix*), three awned grass (*Aristida* spp.), galleta grass (*Hilaria jamesii*), black grama (*Bouteloua eriopoda*), Indian ricegrass (*Oryzopsis hymenoides*), side oats grama (*Bouteloua curtipendula*) and on somewhat more mesic sites mutton grass

Tab
3.f.

S

Juni
Pinu
Pinu
Sita
Oryz

Poa
Agro
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Arte
Chry

Poa
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Cryp
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Erio
Astr
Opun
Arte
Lupi

Spha
Atri
Koel
Cean
Hila

Agro
Vici
Symp
Cowa
Cerc

Ephe
Amel
Stip
Agos
Aste

Fest
Gray
Ribe
Euro
Cirs

Seni
Cast
Bals
Cryp
Stip

Euph
Seni
Elym
Agro
Phlo

Delp
Tetr

low elevations. Arizona fescue (Festuca arizonica) is found occasionally at mid and high elevations.

Several species, notably western wheatgrass (Agropyron smithii), Sandberg bluegrass (Poa secunda), Phlox spp. and Aster spp. were more often found in the central and north sub-provinces. Also in the central and north sub-provinces on better sites (higher elevations) were found bluebunch wheatgrass (Agropyron spicatum), beardless wheatgrass (Agropyron inerme) and snowberry (Symphoricarpos spp.).

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Table 3.f.1 Average composition percentage and consistency of woodland tree species and understory species of the Escalante-Sevier province. Note how certain understory species are found primarily in the latitudinal sub-province divisions.

Species	South sub-province				Central sub-province													North sub-province																X̄ percent composition	Percent construction
Stand number	279	280	270	80	140	93	87	259	171	178	181	104	103	211	358	212	350	97	94B	251	183	187	95	248	191	186	101	250	100	98	190	184	189		
	Abundance classification																																		
Juniperus osteosperma	100	61	100	91	100	47		100	100	85	100	100	55	100	53	42	22	88	75	57	100	100	100	100	100	100	50	47	61	100	93	100	62	78.5	97
Pinus monophylla	P	39		9		53	100			15		P	45		47	58	78	12	25	43			P				50	53	39	P	7		38	2.1	64
Pinus edulis			P						P																										6
Sitanion hystrix	10	2	3	7	5	2		4	18	13	10	5	5	3		1		2	5	5	4	3	5	5	7		1	5	1	1		2		4.1	82
Oryzopsis hymenoides	2	1	20		15	5	12	1	8	15	14	10	10	10	2	5	2	3	13	2	1	2	11			5	4	5	2	1				5.5	82
Poa secunda		1				3	3	2		2	3	6	5					35	10	55	2	7	10	15	2	3	2	15	5	5	15	28	75	9.4	73
Agropyron spicatum						9	1	6	5	5	5	17	10		18		18	7	50	10	33	3	30		7	13	10		10	60	65	P		11.9	70
Phlox spp.		5	3				2	5		1	3		5	2		P		7	5	P	4	1		27	2	5		20	7	15	P	30		4.5	67
Artemisia tridentata	35	1		5		28	5	42	5		35	3			20		68	19			2		2	5	10		55					P		10.3	55
Chrysothamnus viscidi florus	8		1		8	10		15		23	7			15	28			7	1	2		3	10	1	10	30	5							5.6	55
Poa nevadensis		5		2			2		2			1						2	6	18	40	3	2	10	2	12		5			5	20		4.1	52
Purshia tridentata	12	67		3		20		6	2		10		12		30			2										10		5	8			5.7	39
Artemisia tridentata nova				61	48					15		47	50	58		73			4						40				53	10	2			14.0	36
Cryptantha spp.		1	1			P	12	1		5	1		2			1										2								.8	30
Stipa comata	3		2		2	1	1		2					2									2			2								.5	27
Eriogonum spp.	23		1				1	2			1													15										1.3	18
Astragalus spp.	2			1																2				6				1						.4	15
Opuntia spp.		2				5												3	1															.3	12
Artemisia tridentata arbuscula			64																			66				15								4.4	9
Lupinus spp.	P		P																	P														P	9
Sphaeralcea spp.	2		1						8																									.3	9
Atriplex canescens					12					15																								.8	6
Koeleria cristata		4		1																													5	.3	9
Ceanothus greggii				15																														.5	3
Hilaria jamesii					8																													.2	3
Agropyron subsecundum	6							1																										.2	6
Vicia spp.	5																																	.1	3
Symphoricarpos longiflorus						1	40										4				15												5	2.0	15
Cowania stansburiana		1													1	20																		.7	9
Cercocarpus ledifolius							10										6												2					.5	9
Ephedra spp.						7			1	2																								.3	9
Amelanchier alnifolia						1	11																											.4	6
Stipa thurberiana																		2		1														.1	6
Agoseris spp.														1	2																			.1	6
Aster spp.								1	1																									.1	6
Festuca idahoensis									1															1										.1	
Grayia spp.														5																				.1	3
Ribes spp.							5																											.1	3
Eurotia lanata														3																				.1	3
Cirsium spp.							1																											.03	3
Senicio serra							1																											.03	3
Castilleia spp.							1																											.03	3
Balsamorhiza sagitata																				2	5	3									5			.5	12
Cryptantha flava																			2		5						1		3					.3	12
Stipa columbiana						1															1	T			3									.1	12
Euphorbia spp.												1											2	8										.3	9
Senicio uintahensis								3																	3								5	.3	9
Elymus condensatus						2												1	2															.1	9
Agropyron smithii	1																	2								1								.1	9
Phlox longifolia																					1	1												.1	6
Delphinum spp.																								1				1						.1	6
Tetradyma canescens																											2							.1	3

Table 3.f.2 Average composition percentage and consistency o

							rth sub-province															X̄ percent composition	Percent construction
Stand number	169	300	45	48	338		197	247	319	320	146	323	195	192	43	325	246	322	324	145	245		
Species																							
Juniperus osteosperma	18	18	75	19	8	15	25	23	100	100	19	11	41	35	21	25	27	12	11	88	29	37.5	98
Pinus edulis	82	82	25	81	92	85	75	77			81	89	59	65	79	75	73	88	89	12	61	62.4	93
Juniperus scopulorum																							2
Oryzopsis hymenoides	3	15		P	30			3	20	20	10	3		5	10	10	10	10	8	25		8.1	72
Poa fendleriana	5	1	3	16	5	40	10					2	20		30							13.0	69
Sitanian hystrix	5	8	2	2	8	7			28	10	2	5			5			10	P	5		5.5	59
Opuntia spp.	1		4			1		5	2						1		5	5			10	3.3	52
Artemisia tridentata	7				2		20	10	15	4			10			5	28	10				6.4	41
Bouteloua gracilis	34				5		25						10	2	5	13	5	40			5	4.6	39
Carex spp.	3		3		5	10		5			3	15	5	25	5				14	10		2.6	39
Cercocar pus montanus		10				9		2			45	20							15	35		5.4	36
Cryptantha spp.	1	3				2	1	2			3			4			P			3		.9	34
Amelanchier alnifolia		5			1	9				P	4	15					P		15			3.1	33
Gutierrezia sarothrae	15	P			5	5	3			3												1.5	26
Purshia tridentata		5	25	15														10				1.6	26
Solidago spp.		20	5		25							10							35			3.6	26
Koeleria cristata		15					5		5				20			27						1.9	25
Artemisia tridentata arbuscula			10												10						10	2.5	23
Quercus gambelii				40	2																	2.7	20
Gilia spp.	P	P	5												1			3				.3	20
Artemisia tridentata nova	7			10		2						5	5									1.0	16
Chrysothamnus viscidiflorus	5										1			5								1.0	16
Eriogonum spp.	2			1							P											.1	16
Penstemon spp.		2		5					5	2				1								.6	16
Astragalus spp.								2														.6	10
Artemisia frigida	1																					.1	5
Cryptantha flava			1																		5	.2	5
Stipa columbiana																						.2	3
Yucca spp.			5		P																	.1	9
Festuca arizonica		10	32	2		3																.9	9
Hilaria jamesii																						2.0	8
Chrysothamnus spp.				3																		.2	7
Aristida longiseta																						.9	7
Senicio uintahensis																						.3	7
Erigeron spp.				2																		.1	7
Lupinus spp.			1							2												.1	11
Sporobolus cryptandrus					2																	.1	5
Vicia spp.	1		2																			.1	5
Artemisia ludoviciana				2																		.03	2
Agropyron spicatum																						.1	5
Ephedra spp.																						.03	3
Arctostaphylos spp.																						.03	2
Chrysopsis villosa																						.6	2
Festuca spp.																						.03	2
Castilleja spp.																						P	2
Agropyron smithii							8	35		40			12	5	10	12	40				40	4.6	36
Phlox spp.							10	20	5	3	2	20	5	10			5				5	2.2	30
Stipa comata		1					17		5	5						25						1.9	21
Symphoricarpus spp.												5							5			.8	14
Hymenoxys argentea	5																					1.2	9
Poa spp.													5									.9	8
Phlox longifolia									7													.3	6
Aster spp.																						.1	6
Sphaeralcea spp.							P		3							2						.1	6
Balsamorhiza sagitata									P													.1	6
Bahia dissecta																						.1	5
Senicio spp.		P																				P	5
Chrysothamnus nauseosus																						.1	3
Eriogonum spp. (shrub)																						.1	3
Peraphyllum ramosissimum																						.2	3
Psoralea spp.								5														.1	3
Agropyron inerme											30		3	35	20			10	8	10	5	4.6	24
Poa secunda									2	2				8								.6	18
Penstemon spp. (shrub)								3								5						.4	8
Haplopappus gracilis																				12		.4	5
Eurotia lanata							P			2												.03	3

Table 3.f.2 Average composition percentage and consistency of woodland tree species and understory species of the La Sal province. Note how certain understory species are found primarily in the latitudinal sub-province divisions.

Species	South sub-province																	Central sub-province																			North sub-province																									$\bar{X}$ percent composition	Percent construction
Stand number	169	300	45	48	338	4	393	166	47	336	36	37	46	51	167	406	332	5	347	1	349	7	150	342	349B	151	161	348	296	157	340	346	41	164	163	160	148	193	147	149	143	196	194	42	144	321	197	247	319	320	146	323	195	192	43	325	246	322	324	145	245		
	Abundance classification																																																														
Juniperus osteosperma	18	18	75	19	8	15	33	35	71	56	38	7	38	84	17	21		44	65	17	54	30	16	31	31	13	57	18	32	22	11	42	51	50	62	13	22	11	23	43	100	70	38	40	100	65	25	23	100	100	19	11	41	35	21	25	27	12	11	88	29	37.5	98
Pinus edulis	82	82	25	81	92	85	67	65	29	44	62	93	62	16	83	79	100	56	35	83	46	70	84	69	69	87	43	82	68	78	89	58	49	50	38	87	78	89	77	57		30	62	60		35	75	77			81	89	59	65	79	75	73	88	89	12	61	62.4	93
Juniperus scopulorum																																										P																					2
Oryzopsis hymenoides	3	15		P	30		3	2		15	10	10				25		4	10	3	38	10	1		36	2	9	5	20			10	30				5	5	15	10	5	1	2	3	24	8		3	20	20	10	3		5	10	10	10	10	8	25		8.1	72
Poa fendleriana	5	1	3	16	5	40		3	68	35	10	45	77	17	50	25		2	43			10	6	5	20	43	9	30		25	8	3	30			5	10	10	5	14	3	19	19	12	2		10					2	20		30							13.0	69
Sitanian hystrix	5	8	2	2	8	7				32	5	10		15	5	25		2	15			3	1	5	5	5	2		40		7	20	25						5		5	5				3			28	10	2	5			5			10	P	5		5.5	59
Opuntia spp.	1		4			1		5	5		5	3							5	1	2	3	5		2	5	25			10		P	P	7	12	15			1	2	2			2	3			5	2						1		5	5			10	3.3	52
Artemisia tridentata	7				2			2			5	P				5	65	56		8	10						20					20									28	10	2	29		10	20	10	15	4			10			5	28	10				6.4	41
Bouteloua gracilis	34				5		30					5					35		2	9	3	2		5						5		20		25	10			2						7			25						10	2	5	13	5	40			5	4.6	39
Carex spp.	3		3		5	10									5			T					2	P			P	5			3							11	5	10	3	10						5			3	15	5	25	5				14	10		2.6	39
Cercocar pus montanus		10				9		56	P									8				P	10						2		10					73	P	2		2		23	1	3		5		2			45	20							15	35		5.4	36
Cryptantha spp.	1	3				2	P													2	1	10	2		4				2								5		5		2				3	2	1	2			3			4			P			3		.9	34
Amelanchier alnifolia		5			1	9		20		8	20	10			30				1					15						5	10						P	20					P							P	4	15					P		15			3.1	33
Gutierrezia sarothrae	15	P			5	5	10												5		3			2						P		5		15	12				2							5	3			3												1.5	26
Purshia tridentata		5	25	15					7	1	P		10										10	5		2		2												2	5	2	1															10				1.6	26
Solidago spp.		20	5		25		2				P					10								30		5	10				40					5		5					15			5						10							35			3.6	26
Koeleria cristata		15							2	2		5	3											P		5					2							5	T				18				5		5				20			27						1.9	25
Artemisia tridentata arbuscula			10																2	32	10	P		25			20	2			10		10	10		2																			10						10	2.5	23
Quercus gambelii				40	2					P	45	10							1				43	2				2			2							6				15																				2.7	20
Gilia spp.	P	P	5					P										1	2	P		3				2			3																										1			3				.3	20
Artemisia tridentata nova	7			10		2																				3											4	10		4					10							5	5									1.0	16
Chrysothamnus viscidiflorus	5													40		P		2		3																	2			2	2										1			5								1.0	16
Eriogonum spp.	2			1						1								P															1									P			P	2					P											.1	16
Penstemon spp.		2		5						1				15						P									3													3							5	2				1								.6	16
Astragalus spp.									3				1					P		3		30																										2														.6	10
Artemisia frigida	1																															P														10																.1	5
Cryptantha flava			1																	2																																									5	.2	5
Stipa columbiana													2																															10																		.2	3
Yucca spp.			5		P				5										1		1				2																																					.1	9
Festuca arizonica		10	32	2		3			5				5																																																	.9	9
Hilaria jamesii							25														25				5									35	30																											2.0	8
Chrysothamnus spp.				3				2						5													4																																			.2	7
Aristida longiseta							15														2													5	30																											.9	7
Senicio uintahensis								5											1						1			12																																		.3	7
Erigeron spp.				2														1	1		P																																									.1	7
Lupinus spp.			1						1	1			2	2																																				2												.1	11
Sporobolus cryptandrus					2		5														1																																									.1	5
Vicia spp.	1		2																				T																																							.1	5
Artemisia ludoviciana				2																																																										.03	2
Agropyron spicatum																				1		5							1																																	.1	5
Ephedra spp.																					1				1																																					.03	3
Arctostaphylos spp.																												2																																		.03	2
Chrysopsis villosa																														35																																.6	2
Festuca spp.																																2																														.03	2
Castilleja spp.																		P																																												P	2
Agropyron smithii																			P	14		10							20								4	2	2	3	2		3	15	2	2	8	35		40			12	5	10	12	40				40	4.6	36
Phlox spp.																		8		P																	4	10	4	4	5		15				10	20	5	3	2	20	5	10			5				5	2.2	30
Stipa comata		1					2													20	1						P												3	3	27				10		17		5	5						25						1.9	21
Symphoricarpus spp.															5								10														2	2				12	2	4								5							5			.8	14
Hymenoxys argentea	5														2											23				2							28			15																						1.2	9
Poa spp.																			5									30	4	10																							5									.9	8
Phlox longifolia																		1	2																			10											7													.3	6
Aster spp.																														6								P			1		2																			.1	6
Sphaeralcea spp.																					1																										P		3							2						.1	6
Balsamorhiza sagitata																								2				P																	1				P													.1	6
Bahia dissecta																										5											P			P																						.1	5
Senicio spp.		P																																					P						P																	P	5
Chrysothamnus nauseosus																		2																										4																		.1	3
Eriogonum spp. (shrub)																											1														5																					.1	3
Peraphyllum ramosissimum																							10																			5																				.2	3
Psoralea spp.																		2																														5														.1	3
Agropyron inerme																																					22		45	28		14		5	40	6					30		3	35	20			10	8	10	5	4.6	24
Poa secunda																		10		P													4				1			1	5			3	2	1			2	2				8								.6	18
Penstemon spp. (shrub)																																					10		P									3								5						.4	8
Haplopappus gracilis																																					3		8																					12		.4	5
Eurotia lanata																																															P			2												.03	3

Table Average composition percentage and consistency of woodland
3.f.3

Species								st sub-province																	X percent composition	Percent construction
	230	231	69	233	134	289	121	400	22	7N	23	115	9N	15A	192	105	398	125	135	314	145	5N	4N	224		
Juniperus osteosperma	90	42	95	65	44	52	100	30		80		90	80		88		78	52	85	93		33	100	22	43.8	87
Pinus edulis	10	58		35	56			70		20	P	10	20		12		23	48	15	7		67		78	37.0	76
Juniperus monosperma									100		100			100		100					53				9.3	13
Pinus monophylla			5			48																			1.7	8
Juniperus depeana																					47				3.0	6
Juniperus scopularum																									0.3	3
Bouteloua gracilis	3	20	2	50		19	10	30	25	40	35	82	55	62	72	68	48	89	82	5	75	55	72	65	42.2	93
Gutierrezia sarothrae	39	15	30	30	7		40	3	2	25	10	2	10	10	5	8	5	2	5	33	2	2	5	10	9.8	90
Sitanian hystrix	1	1	P		5	3				2				10				P		15		1			3.5	62
Opuntia spp.	1	1	P	P	2				5	3	20	2			P			P	1	2	1		P		1.1	56
Aristida spp.	5	3	10	1		20		P	P	3		5	9	4	5			4					5		1.5	38
Hilaria jamesii						18	4		25	7	20	2	1			5				44		2	1	15	4.6	37
Poa fendleriana					4																				1.5	32
Oryzopsis hymenoides	10	2	10	3	5	3	4	5																	1.5	32
Yucca spp.	1	15	1	4			10	P				P					P		P						.7	30
Sphaeralcea spp.	2	1	2	3		1	3		10		3														.6	30
Bouteloua curtipendula		1	5	2		3						2		1				P	2		5				1.4	28
Artemisia tridentata										10							20			3		33			4.8	25
Penstemon spp. (shrub)	2			1	5																				1.0	25
Ephedra spp.	1	2	P				2	10																	.5	17
Sphaeralcea spp.								5		3		2	5		5								5		1.1	15
Stipa comata	5		15			17											2								.7	13
Koeleria cristata																									.7	11
Astragalus spp.	5	1																							.5	11
Bouteloua eriopoda	18	18		2		2	8									5									.8	11
Quercus gambelii					1																				1.1	11
Erigeron spp.					1										1								1		.1	10
Poa spp.																					5	2			.3	8
Senicio spp.					1																				.03	4
Amelanchier spp.					1																				.04	4
Solidago spp.					3																				.1	3
Cowania stansburiana				1	16			1		P															.8	28
Berberis fremontii	1	5	2	P		2								2											.3	24
Quercus turbinella	2						2																		1.7	13
Euphurbia	P			P	1		2																		.2	9
Atriplex canescens				1		2	3																		.1	11
Phlox spp.	P	P		2	1																				.1	11
Cryptantha spp.	8	3	3				2																		.2	7
Eurotia lanata			2			3	3																		.1	7
Artemisia tridentata nova					40																				2.6	6
Lycium spp.						2																			.1	4
Stipa spp.			3				4	P																	.1	4
Muhlenbergia rigens	1	5																							.1	3
Solanum spp.				P																					.04	3
Coleogyne romosissima		1																							.01	1
Ceanothus greggi			5																						.1	1
Stipa columbiana					5																				.1	1
Penstemon pachyphyllus																									.02	1
Hymenoxys richardsonii																									.7	13
Rhus trilobata																									.2	8
Blepharoneuron tricholepis																									.1	7
Lupinus brevicaulis																									.2	6
Penstemon eatoni																									.01	3
Ribes spp.											2														.02	1
Sporobolus wrightii																									.03	1
Muhlenbergia wrightii																									P	1
Menodora scabra																									.01	1
Eriogonum spp.									P																.5	11
Chrysothamnus spp.													10												.4	8
Poa pratensis																									.5	7
Cercocarpus montanus																									.8	6
Artemisia frigida																									.3	6
Aster spp.									10		2														.2	6
Festuea arizonica																									.1	4
Arctostaphylos patula																2									.02	3
Castilleja spp.																									P	3
Muhlenbergia torreyi											3		2		3	2			5						.2	7
Purshia tridentata													1												.6	7
Carex spp.																									.3	7
Lupinus spp.																									.03	7
Agropyron smithii									20												5				.7	6
Muhlenbergia pungens								40				1													.9	4
Lycurus phleoides														5		3									.1	3
Penstemon linarioides									3																.1	3
Chrysothamnus viscidiflorus																									.3	1
Nolina spp.														1											.01	1
Cercocarpus breviflorus																									.3	1
Symphoricarpus spp.																									.03	1
Tetradyma spp.																	10								.1	1
Agropyron inerma																									.01	1
Gilia spp.																									P	1
Rhamnus crocea											3														.04	1

Table 3.f.3 Average composition percentage and consistency of woodland tree species and understory species of the Coronado province. Note how certain species are found primarily in the longitudinal sub-province division.

Species	West sub-province																								Central sub-province																East sub-province																															X percent composition	Percent construction
	230	231	69	233	134	289	121	372	127	124	66	133	285	125	122	128	368	371	284	360	369	367	370	380	236	61	238	60	376	64	241	237	363	240	374	239	65	375	366	373	365	9	226	30	399	317	228	316	12	2N	202	227	2H	225	400	22	7N	23	115	9N	15A	192	105	398	125	135	314	145	5N	4N	224		
	Abundance classification																																																																										
Juniperus osteosperma	90	42	95	65	44	52	100	65	84	21	75	29	100	68	100	33	61	50	100	42	31	30	35	72	41	48	28	71	68	50	11	19	80	11	33	7	100	50				48	29	85		22	22	15	60	55	34	4	75	54	30		80		90	80		88		78	52	85	93		33	100	22	43.8	87
Pinus edulis	10	58		35	56			35	16	79	25	71		32		67	39	50		58	69	70	65	27	59	52	72		32		89	81		89		93		50	33		56	52	64	15	35	78	78	85	40	45	63	82	5	46	70		20	P	10	20		12		23	48	15	7		67		78	37.0	76
Juniperus monosperma																												29											67		44				65											100		100			100		100					53				9.3	13
Pinus monophylla			5			48									P															50			20				P																																			1.7	8
Juniperus depeana																																			66					100											3																	47				3.0	6
Juniperus scopularum																																											7									14																				0.3	3
Bouteloua gracilis	3	20	2	50		19	10	33	20	50	50	5	51	33	5	17	50	68	80	53	40	45	62		50	10	58	52	79	18	62	86		45	35	80	33	69	84	56	72	1	50	15	20		59	2		15	65	60	30	70	30	25	40	35	82	55	62	72	68	48	89	82	5	75	55	72	65	42.2	93
Gutierrezia sarothrae	39	15	30	30	7		40	2	P	21	20	1	5	13	16	13	10	10	3	5	2	2	5	14		10	10	10	10		3	3	49	3	30	8		15	5	15	15	10	1	18	10	2	3	10		5		1	10		3	2	25	10	2	10	10	5	8	5	2	5	33	2	2	5	10	9.8	90
Sitanian hystrix	1	1	P		5	3		3	3	2	5	3		1	2	3	10	2		3	5		3		P	1		5	3				10	2	1			5		2		2	1	10	P	25	10	8	3	20	5		2	8			2				10				P		15		1			3.5	62
Opuntia spp.	1	1	P	P	2			4	1	3	1		10	P	1	P	1		2						P		1		P			1				1	1					3	2	5		P	1		4	P	P	P				5	3	20	2			P			P	1	2	1		P		1.1	56
Aristida spp.	5	3	10	1		20		5		2				1					1						10				P	1					2		2		2	3											3		1		P	P	3		5	9	4	5			4					5		1.5	38
Hilaria jamesii						18	4			5		3		15	18									70												5			4			1	6	20	23			3					4	9		25	7	20	2	1			5				44		2	1	15	4.6	37
Poa fendleriana					4			10		P		12				P	8	5		5		14			5	2	5		2			1	3	5				2				3	2			5		5	3	5																						1.5	32
Oryzopsis hymenoides	10	2	10	3	5	3	4	1	4		1		1		P									3																		2	P	10	5	5		20	9	5			5		5																	1.5	32
Yucca spp.	1	15	1	4			10	1	P	1		3	3									3									P		P											P	P						3			2	P				P					P		P						.7	30
Sphaeralcea spp.	2	1	2	3		1	3	2			2	P	3	2	2				1	2					1													2				1		3										P		10		3														.6	30
Bouteloua curtipendula		1	5	2		3		20			5								5							3			P	1	5		3		20		8			10																			2		1				P	2		5				1.4	28
Artemisia tridentata									5	10			10	30	40	60	14					7	15											5								7			52			10		10							10							20			3		33			4.8	25
Penstemon spp. (shrub)	2			1	5			1									1				2				2	30	1	2						2									5	5		5	2	P	2			2																				1.0	25
Ephedra spp.	1	2	P				2		1				1	2		2																												5	1				10						10																	.5	17
Sphaeralcea spp.													3		50					P																															3			P	5		3		2	5		5								5		1.1	15
Stipa comata	5		15			17			P												P																								2					5			3											2								.7	13
Koeleria cristata																		5			20		5					3					2					2								5				10																						.7	11
Astragalus spp.	5	1														1						20					1							3								1					1																									.5	11
Bouteloua eriopoda	18	18		2		2	8				4																										2																										5									.8	11
Quercus gambelii					1													P			1																					45	5			22					3	1																				1.1	11
Erigeron spp.					1												P							2			1													1																						1								1		.1	10
Poa spp.																								2																	2						5				4																	5	2			.3	8
Senecio spp.					1																														1							P																														.03	4
Amelanchier spp.					1																														1														1																							.04	4
Solidago spp.					3																																							3																												.1	3
Cowania stansburiana				1	16			5	5			3	T				1			10		3	2	1	5	P			P	1									P						2								2		1		P															.8	28
Berberis fremontii	1	5	2	P		2			P	1	3		1			1		2							3			P	P							1		P																							2											.3	24
Quercus turbinella	2						2	10										2								20				30			5		5		45																																			1.7	13
Euphurbia	P			P	1		2					1														5		2																																												.2	9
Atriplex canescens				1		2	3				1								P																			P							P									P																		.1	11
Phlox spp.	P	P		2	1					1		2																			P	P												P																												.1	11
Cryptantha spp.	8	3	3				2																																																																	.2	7
Eurotia lanata			2			3	3				1								1																																																					.1	7
Artemisia tridentata nova					40				55			70								20																																																				2.6	6
Lycium spp.						2					5								4																																																					.1	4
Stipa spp.			3				4																																																P																	.1	4
Muhlenbergia rigens	1	5																																																																						.1	3
Solanum spp.				P										3																																																										.04	3
Coleogyne romosissima		1																																																																						.01	1
Ceanothus greggi			5																																																																					.1	1
Stipa columbiana					5																																																																			.1	1
Penstemon pachyphyllus										2																																																														.02	1
Hymenoxys richardsonii																									5	4	10	8	5		4	9				3								2																												.7	13
Rhus trilobata																														10			1		2		5				P										1																					.2	8
Blepharoneuron tricholepis																									5		2		1			P				P																																				.1	7
Lupinus brevicaulis																									13											1			1		1																															.2	6
Penstemon eatoni																															1			T																																						.01	3
Ribes spp.																																																										2														.02	1
Sporobolus wrightii																												3																																												.03	1
Muhlenbergia wrightii																												P																																												P	1
Menodora scabra																										1																																														.01	1
Eriogonum spp.																										10				4			17				4			1							1		2							P																.5	11
Chrysothamnus spp.																											3					1															2					P	10							10												.4	8
Poa pratensis																															5			25									2									4		2																		.5	7
Cercocarpus montanus																														5												1	3						51																							.8	6
Artemisia frigida																											P			20																1	2																									.3	6
Aster spp.																																										1	P													10		2														.2	6
Festuea arizonica																																3										3					1																									.1	4
Arctostaphylos patula																														1																																	2									.02	3
Castilleja spp.																									P																													P																		P	3
Muhlenbergia torreyi																																																										3		2		3	2			5						.2	7
Purshia tridentata																																										5				5		20	15											1												.6	7
Carex spp.																														P												7	10							5		2																				.3	7
Lupinus spp.																					P																					2				1		P	P																							.03	7
Agropyron smithii																																																		5		17				20												5				.7	6
Muhlenbergia pungens																																																					25		40				1													.9	4
Lycurus phleoides																																																													5		3									.1	3
Penstemon linarioides																																																						2		3																.1	3
Chrysothamnus viscidiflorus																																													25																											.3	1
Nolina spp.																																																													1											.01	1
Cercocarpus breviflorus																																																20																								.3	1
Symphoricarpus spp.																																											2																													.03	1
Tetradyma spp.																																																																10								.1	1
Agropyron inerme																																											1																													.01	1
Gilia spp.																																														P																										P	1
Rhamnus crocea																																																										3														.04	1

(Poa fendleriana) is found. Common shrubs and forbs are big sagebrush Artemisia tridentata), Yucca spp., snake weed (Gutierrezia sarothrae), globe mallow (Sphaealcea spp.) and at the upper elevational extremes, gambel oak (Quercus gambelii).

Unlike the other two provinces, the vegetational changes occur longitudinally instead of latitudinally. Preponderance of summer precipitation decreases as one travels westward, which may account for the different species in the sub-provinces (Table 3.e.3).

Of the plants that are concentrated on the west and central sub-provinces, these appear to be the most important: cliffrose (Cowania standsburiana), Algerita (Berberis fremontii), live oak (Quercus turbinella) and Phlox spp. Ring grass (Muhlenbergia torreyi), wolf tail (Lycuras phleoides), bitter brush (Purshia tridentata and birch leaf mahogany (Cercocarpus montanus) mainly occur in the central and east sub-provinces. At higher elevations, squawbrush (Rhus trilobata), rubber plant (Hymenoxys richardsonii), pine dropseed (Blepharoneuron tricholepis), Arizona fescue (Festuca arizonica), Kentucky bluegrass (Poa partensis), and manzanita (Artostaphylus patula) occur.

This study indicates distribution of precipitation as probably being the most important single factor in the division of provinces. And when coupled with temperature influences, precipitation accounts for the general vegetation composition changes throughout the study area.

Assuming present range conditions, woodland sites in the Coronado province generally out-produce similar sites in the other two provinces in both understory production and individual tree production. However, woodlands seeded to introduced grass species are far more productive in the Escalante-Sevier and La Sal Provinces. Seasonal precipitation distribution does not favor seeding grass species in the Coronado province. The climatic pattern and local soil conditions within the latter province may discourage any seeding practice. Response of the understory native species to land treatment appears to be different also. Bunchgrass understory increases production following tree removal treatments through a gain in vigor (of the existing plants) and through additional production from new plants. Following tree removal, shortgrass species appear to gain (in vigor only) for several years. Increases in ground cover seem to require a long time for materialization.

Generalizations for the woodland type may be made only within certain limits. Great caution is needed, however, when transferring a management practice common to one area to another. The proposed province alignment provides a basis for comparing management potentials for pinyon-juniper woodlands throughout the study area.

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4. SITE CLASSIFICATION OF THE PINYON-JUNIPER WOODLANDS

Site quality is measured by the productivity of the land when it is used at full capacity. Productivity at full capacity is a function of the many site factors which influence growth. Forest stand conditions are rare which will permit a direct estimate of site quality by means of measuring the actual crop produced by the site. Yield tables for particular species have been constructed by searching for stands which appear to be fully stocked for their age but they are only applicable to pure, even-aged stands. A yield table provides a means of estimating how fully stocked a particular stand may be only if the site quality is already known. Because volume production is subject to variation from changes in density, height growth has gradually attained acceptance as the most independent measure of the quality of a site. Though height growth is affected adversely by low density stocking and young trees have frequently shown a higher growth rate than the site can maintain to maturity, in general, the height to which a tree will grow at a particular age is used as an index of site quality.

The height-age relationship is unsatisfactory for use in uneven-aged stands as a 50 year old tree may be 3 feet or 50 feet tall, depending upon whether it was suppressed by an overstory or free to grow without overhead competition. An alternative measure has been suggested and developed for red spruce by McLintock and Bickford [1957]: the height attained when a tree reached a particular diameter.

Stands in the pinyon-juniper type are not even-aged, are composed of varying proportions of pinyon and juniper, and rarely approach what could be called full-stocking. In fact, most stands are moderately open and become increasingly so on the poorer sites. The uneven-aged character of the stands precludes the use of the height-age relationship for developing a site index for classifying site qualities. By contrast, the height-diameter relationship provides a sound basis for pinyon-juniper site classification.

4.a. Pinyon Site Index Curves--T. W. Daniel

After the first field season, the heights over diameters-at-one-foot for trees selected on or around each plot, which were judged as having typical forms for the height-diameter curve, were plotted by species. The curve was drawn by ocular estimate.

Where a reasonable number of "curve trees" had been available at a plot, there was usually a clear-cut best fit especially between 6 to 14 inches in diameter. Below 6 inches and sometimes above, the trees on some plots were frequently either taller or shorter than expected for their diameters. It was often the case that the too tall tree was quite old for its diameter. The same tree, when plotted on the height-age or diameter-age curves, was shorter and smaller in diameter than expected for its age. The abnormality is attributed to suppression as such a tree usually showed evidence of having come up through competition. Another exception was the occasional fine-branched, thin-crowned, even short-crowned tree that would be quite tall and slender when obviously open grown. The short tree for its diameter was a broad bushy type and young for its diameter. Above 14 inches in diameter, the form of the tree had a significant influence on its height-diameter relationship. As has been indicated, the "site tree" was picked for its maturity and the tallest mature or overmature was selected where a choice was available. A tree that maintained a single main stem throughout its life maintained a growth rate comparable to the younger tree (Figure 4.a.1). The closer to the ground that the main stem lost its dominance and the more the upper crown branched, then the greater was the loss in height relative to the growth rate indicated by younger trees. A dense stand has less reduction in height for a given loss of main stem dominance than does a more open stand. This dependence of the height-diameter relation upon the form of the tree,

Figure 4.a.1

Site tree form
follows growth pattern
of younger trees

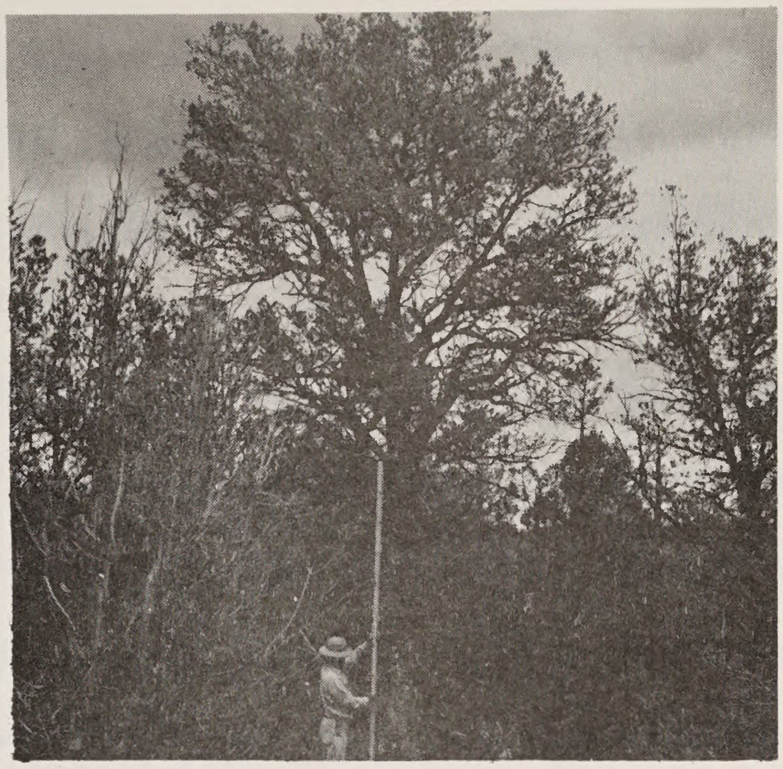


Figure 4.a.2

Site tree form
agrees with "flattened"
growth curve

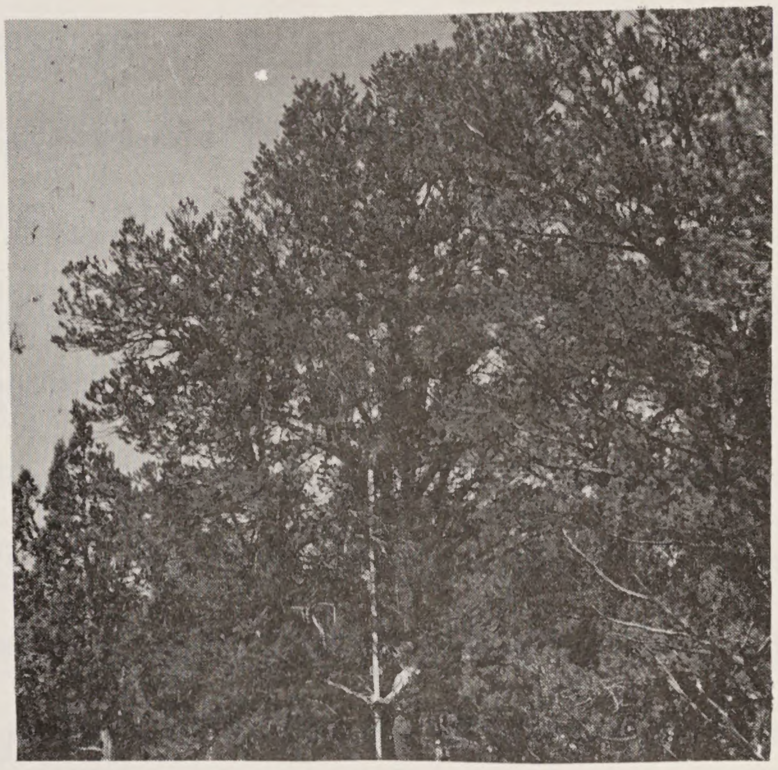
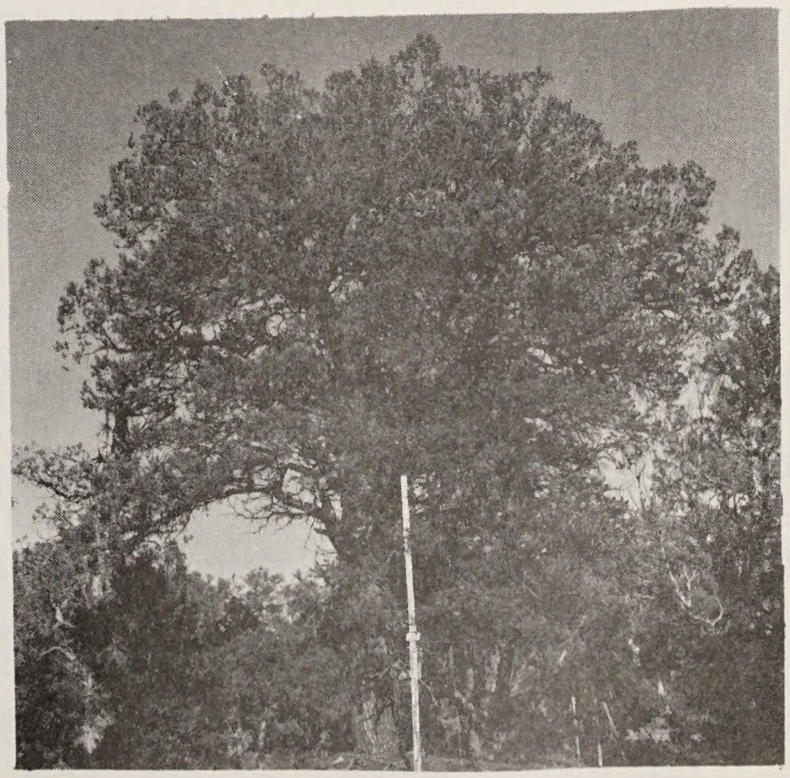


Figure 4.a.3

Site tree form
holds height below "flattened"
growth curve



especially in the large diameters, made the height-diameter curve for a plot include a large judgment factor for the larger diameter trees. A picture was taken of most "site trees" and the height-diameter curve was weighed somewhat by the estimated depression of the height because of form. Figure 4.a.2 shows a form that puts the tree on the curve if it becomes flattened after 14 inches in diameter while Figure 4.a.3 shows a form that drops the tree well below even a flattened curve. As an example, on one plot the "site tree" was 41 feet tall, yet there were no trees above 34 feet even though they had larger diameters. In this instance the curve of height-diameter was flat because of the many short larger diameter trees, but the tall "site tree" with its single main stem to the top agreed with the projection of the trend of the younger trees.

The height of the height-diameter curve was recorded for 6, 10, 25 inches diameter at one foot above the ground for every plot during the winter of 1964-5. A multiple correlation was run using the heights at 6 inches as the dependent variable and 33 site characteristics as independent variables. The analysis was repeated using the heights at 10 inches and again for heights at 25 inches. The independent variables explained 59% of the variation in height of the pinyon pines at 10 inches in diameter, 57% of 6 inches, and 52% at 25 inches. An analysis of the relationship between the heights on the curves at 10 inches and 12 inches with the data of two years showed a 98% correlation. The smallest diameter that is compatable with reliability should be selected for use in establishing the site index because smaller trees are more frequent than the larger ones. In conclusion, the site index diameter will be 10 inches at one foot above the ground line and site index is defined as the height to which a tree will grow on a particular site in the time it will take the tree to each 10 inches diameter.

The height-diameter curves of each plot were traced on a common transparency by species and the curves of each province were traced on separate sheets. A family of site index curves was constructed for each species and for two of the provinces. Several trials attempting to compromise the flattened curves with the continuously rising curves produced site index readings at variance with some strong plot curves. After the decision to accept the continuously rising curves as the basis for determining the site index of a plot, the differences among the provinces were eliminated.

A single family of site index curves are presented for use with the two species of pinyon and applicable to the entire study area (Figure 4.a.4).

In using the site index chart, a transparent piece of graph paper with the same scale as the chart is used for plotting the heights over diameters for trees of various diameters distributed over the site for which the site index is needed. A free hand curve should be sufficient to match the appropriate site index curve when the transparency is laid on the site index chart. The more dominant the main stem of a tree, the more reliably is it likely to indicate the site index. The broken lines that take off from the site index curves represent the flattening that commonly occurs, and caution is urged in interpreting such curves. On poor sites, young trees often grow as fast as on good sites. It is probable that the young trees do not reflect the limitations of the site which the older trees do. Trees smaller than 6 inches in diameter are too erratic to be sensitive indicators and in some instances the same may almost be said for the very large diameters.

It would be confusing to have two site indices for a given area--one for pinyon and one for juniper. In addition, pinyon grows more uniformly on all sites, and is more likely to have a well developed single stem for a more accurate measurement of diameter and a more sensitive site index curve. Pinyon dominates the majority of the pinyon-juniper type within the study area. For these reasons, in addition to the greater erraticness shown by juniper when growing mixed with pine, there is only one site index offered for the type-pinyon site index. The pinyon site index is used even for pure juniper sites by converting the height of the 10-inch juniper from the juniper height-diameter chart

(Figure 4.a.5) to a pinyon site index by applying the correction from the pinyon 10 inch curve-juniper 10 inch curve chart (Figure 4.a.6).

of

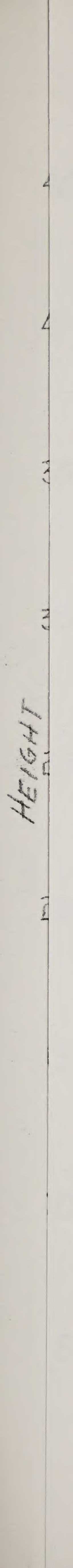
The family/juniper height-diameter curves (Figure 4.a.5) was constructed in the same manner as the pinyon family and the chart is applicable to juniper throughout the study area. The true relation between Juniperus monosperma and Juniperus osteosperma site curves is not certain because there were too few plots with Juniperus monosperma and their height-diameter curves could not be distinguished from those of Juniperus osteosperma. The other junipers that were found on occasional plots--J. scopulorum and J. deppeana--had similar curves, but each curve was based on too few points for reliability.

4.b. Height-Age and Diameter-Age Curves by Site Indices, Species and Provinces--T. W. Daniel

The annual rings of each cross-sectional disk from a range of diameters on each plot were counted. There was a total of 2401 cross-sections counted on three radii each. Pinyon annual rings were readily counted. Annual rings on juniper disks were difficult to count in spite of a good sanding technique; however, one person counted the bulk of them, so a reasonable uniformity was achieved in the counts.

A preliminary plotting showed no differences in height-age or diameter-age between the two pine species and practically all the Juniper disks were J. osteosperma. The pine disks were grouped under each's tree height or diameter within the site index of the plot from which they were taken. A disk from site index 20 was tabulated in the site index 20 column according to its tree's height or its diameter. This procedure tended to smooth some of the variation as there could be eight disks from site index 20 which were cut from 16 foot trees. When plotting each point, groups points were weighed more heavily in determining the location of the curve than the more variable single values.

The height over age or diameter over age data were plotted within a site index. All the points from groups of three site indices (14, 15, 16, or 17, 18,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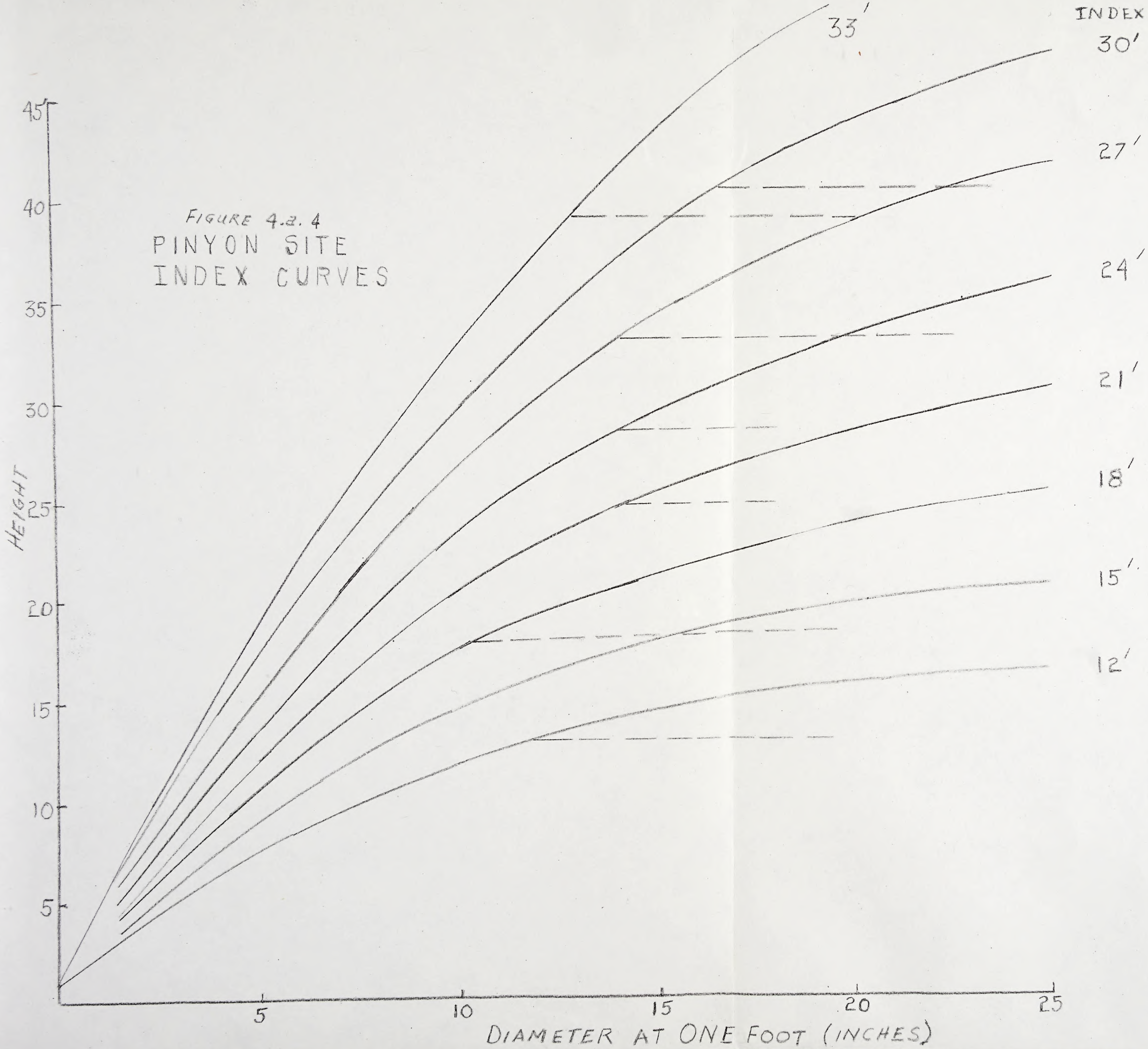


FIGURE 4.a.4
PINYON SITE INDEX CURVES

HEIGHT

FIGURE 4.2.5

JUNIPER

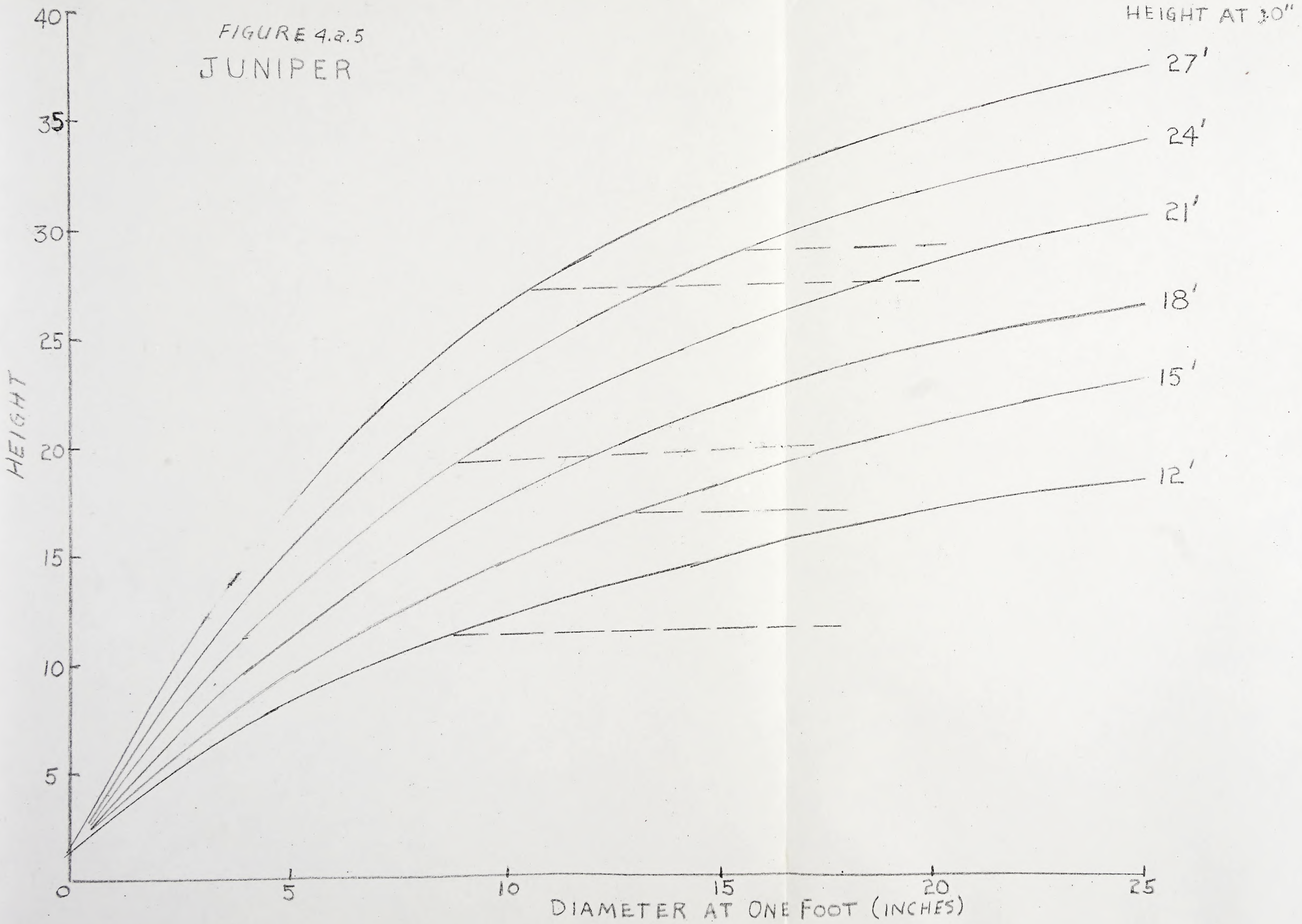
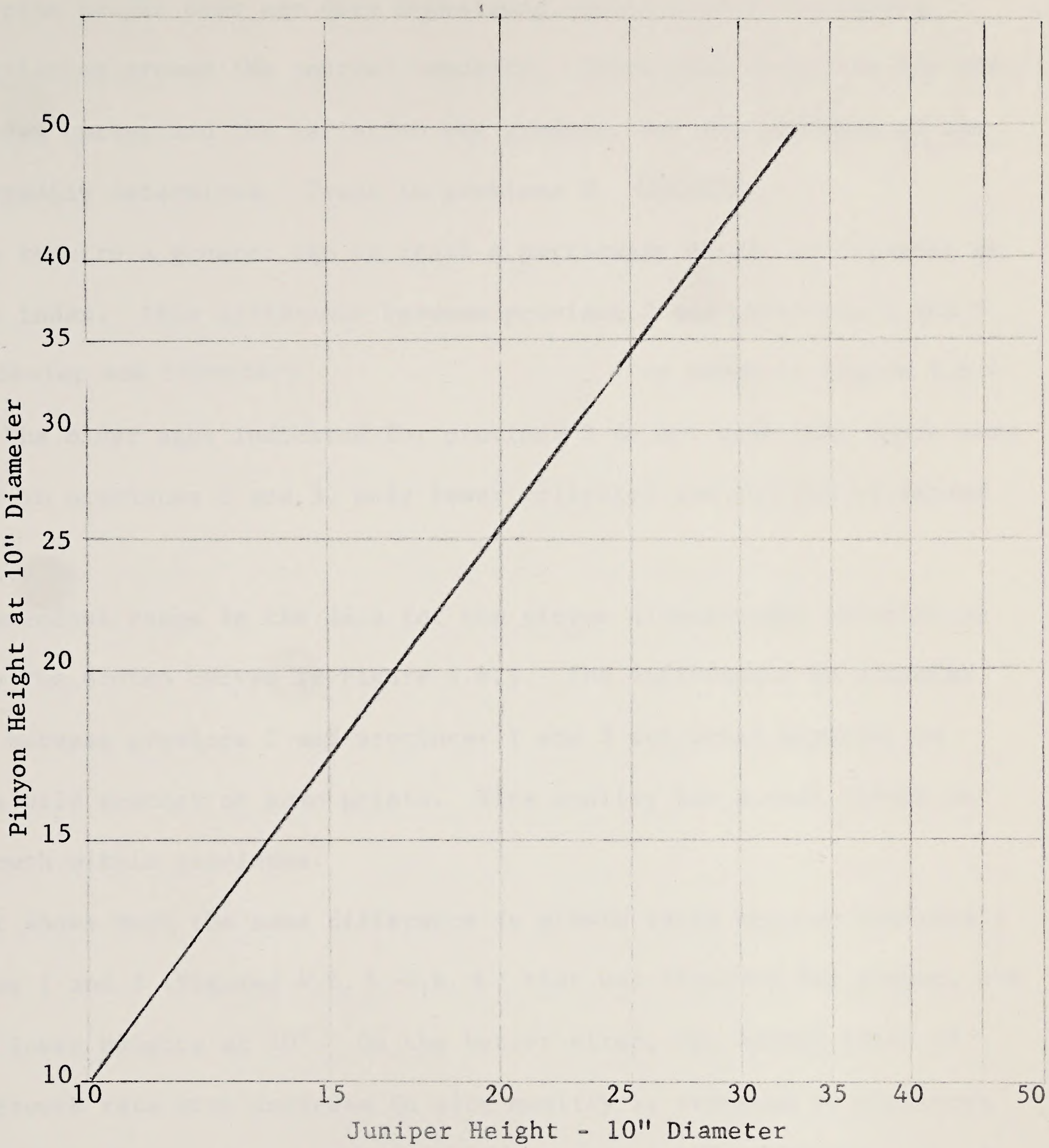


Figure 4.a.6.
Pinyon-Juniper Height Relationships
at 10" Diameter Class* (All Zones)



* Diameter at 1' above ground level

$Y = -\log 2.28 + 1.3579 (\log X) \quad R^2 = 0.968$

19 etc.) were balanced around a single curve, then the next higher site indices were plotted and curved. By this means, the relationships shown in Figures 4.b.1 through 4.b. 8 were established.

Pinyon pine height over age data made strong curves with a reasonable amount of variation around the central tendency. There were less data for the high site index curves and the variation was greater, but the position of the curves was readily determined. Trees in province 2 (La Sal) consistently require a greater age to reach a particular height or diameter at a given site index. This difference between province 2 and provinces 1 and 3 (Escalante-Sevier and Coronado) is shown in Figure 4.b.1 and 4.b.2. The older ages indicated for province 2 do not mean that there were no old trees in provinces 1 and 3, only fewer collected and too few to extend the curves.

The tremendous range in the data for the pinyon diameter-age relation is indicated by the broken curves in Figure 4.b.3. The differences in diameter growth rate between province 2 and provinces 1 and 3 are quite apparent in spite of the wild scatter of some points. Site quality has a real effect on diameter growth within provinces.

Juniper shows much the same difference in growth rates between province 2 and provinces 1 and 3 (Figures 4.b. 4 -4.b. 8) that was observed for pinyon, but only at the lower heights at 10". On the better sites, the normal trend of increasing growth rate with increase in site quality is reversed in provinces 1 and 3. Diameter growth increases up to a juniper height at 10" diameter of 18' in province 1 (Figure 4.b. 6) then decreases with increasing quality of the site. The same effect is observed in province 3 (Figure 4.b. 8) to a lesser degree and is not apparent in Figure 4.b. 7. The data for the diameter-age relation varied so much that the three provinces were plotted separately.

The drop in the height growth rate for the juniper in provinces 1 and 3 (Figure 4.b. 5) on the better sites as well as the more erratic quality of of the juniper data support the decision to refer only to the pinyon site index. In province 2, the juniper height-age relation follows the normal pattern except for the best site.

Juniper's reversed response to site improvement for the height-age and diameter-age relationships could be caused by the increasing aggressiveness of the pinyon on the higher quality sites. This is illustrated by the data of Figure 4.b.6 where the height of the juniper at 10 inches on poor sites is almost the same as the pinyon pine. When the site index increases for pinyon pine, the height of juniper at 10" relative to the pinyon pine's height falls rapidly.

4.c. Tree Height-Crown Diameter and Site Index Correlation--R. J. Rivers

The general dependence of tree growth on crown diameter and rate of photosynthesis has become a well-established axiom [Baker, 1950]. More specific association of crown diameter with such characteristics as d.b.h. and tree height probably vary with species, age, and site. Specific studies involving crown diameter-d.b.h. relationships have been carried out on Red Alder [Apsey, 1962] and White Spruce [Vezina, 1962]. One of the studies conducted in even-age spruce stands indicated that the degree of linearity was significant when the areas were divided into site classes [Liebold, 1963]. Crown dimensions and similar characteristics have also been used to predict cone production in such species as _Pinus sylvestris_ [Thorbjarsen, 1960].

The main application of crown diameters has been in determination of stand volumes. This relationship has been developed for such species as _Populus deltoides_ and _Pinus sylvestris_ [Ilvessalo, 1950; Berlyn, 1962]. More recent utilization of crown diameter-tree volume relationships has been in the field of photo interpretation [Spurr, 1948]. Aerial volume tables for the Pinyon-Juniper Type were developed by Moessner in 1962. This latter work presents

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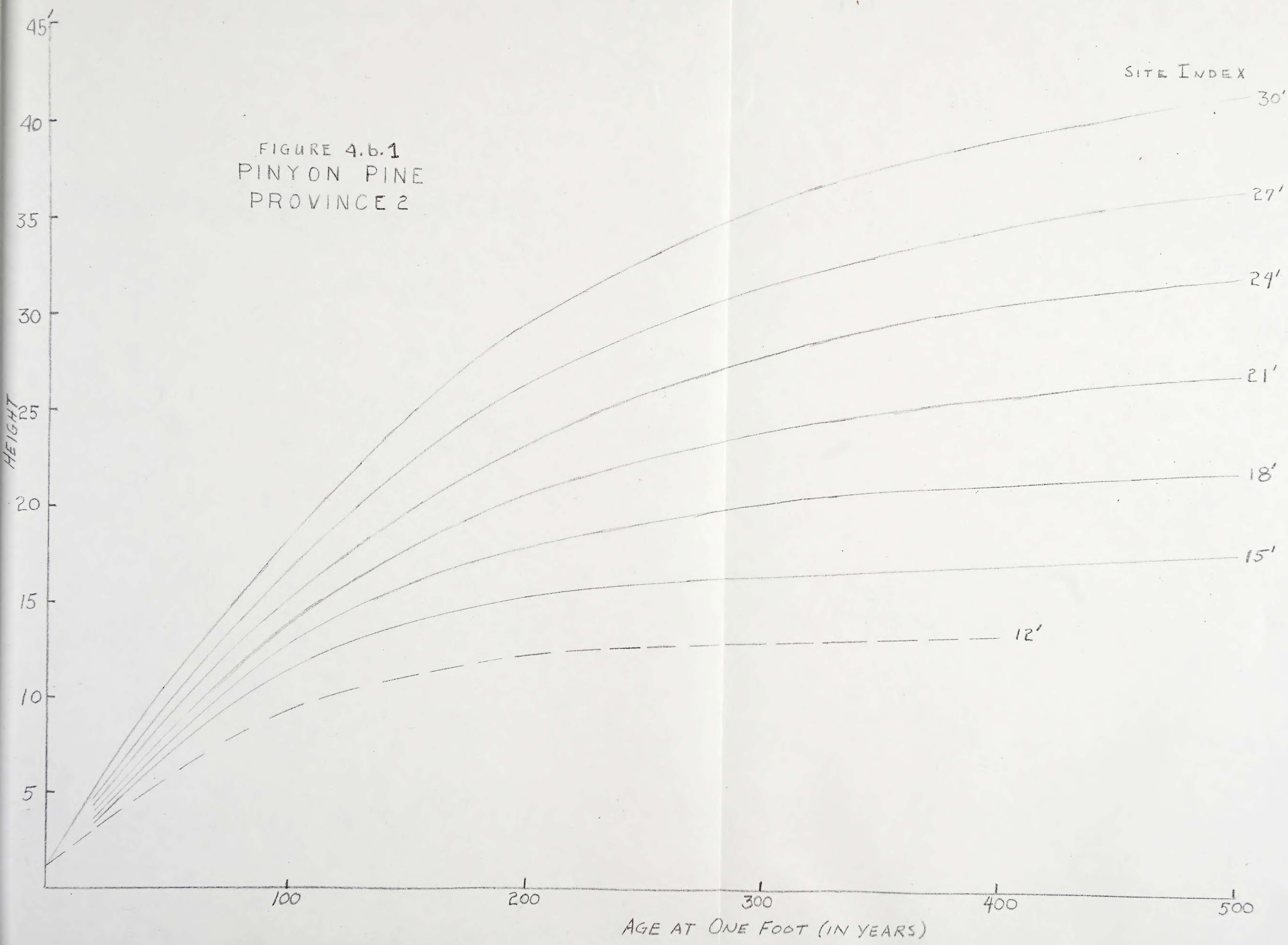
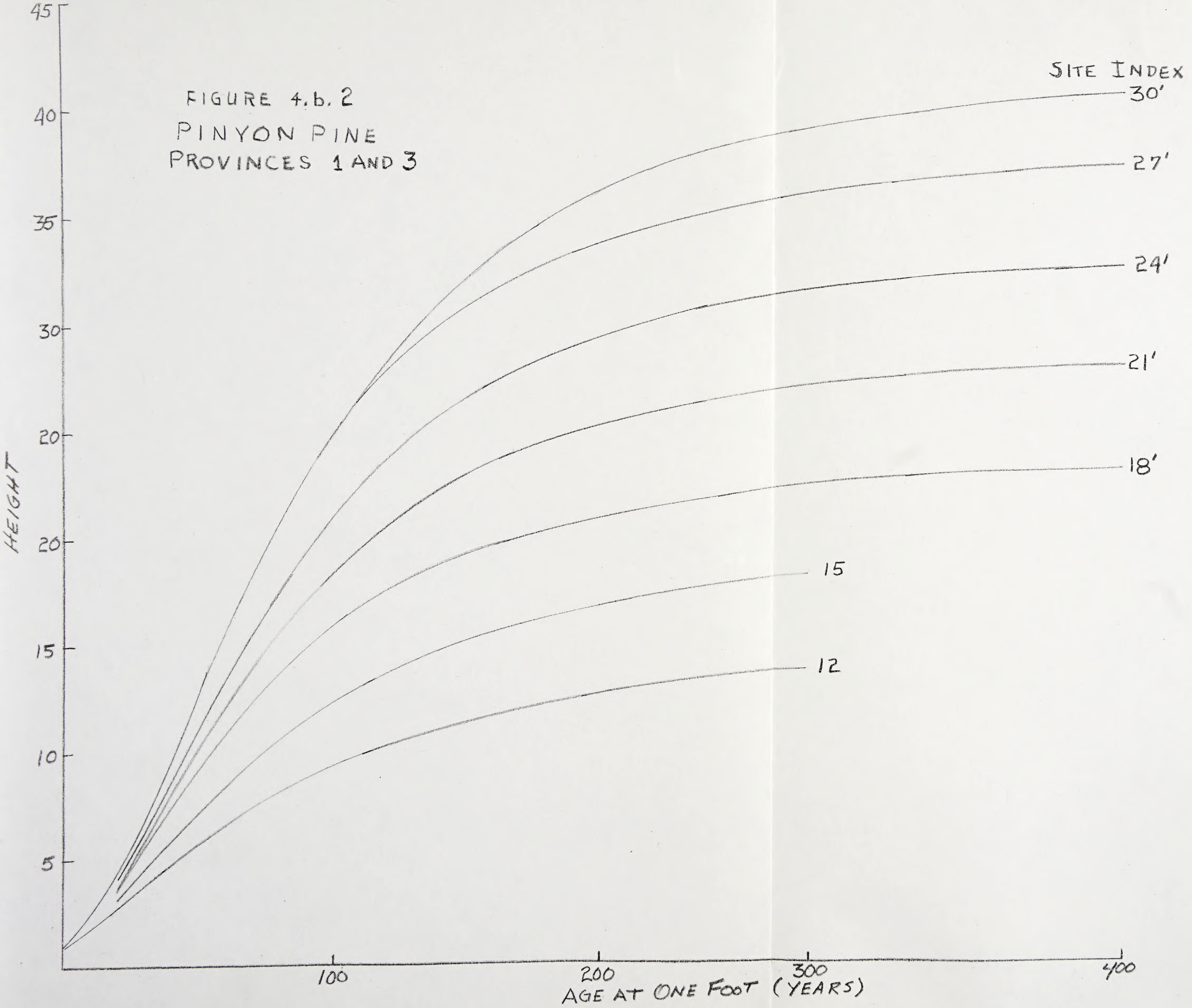


FIGURE 4.b.1
PINYON PINE
PROVINCE 2

HEIGHT

FIGURE 4.b.2

PINYON PINE
PROVINCES 1 AND 3



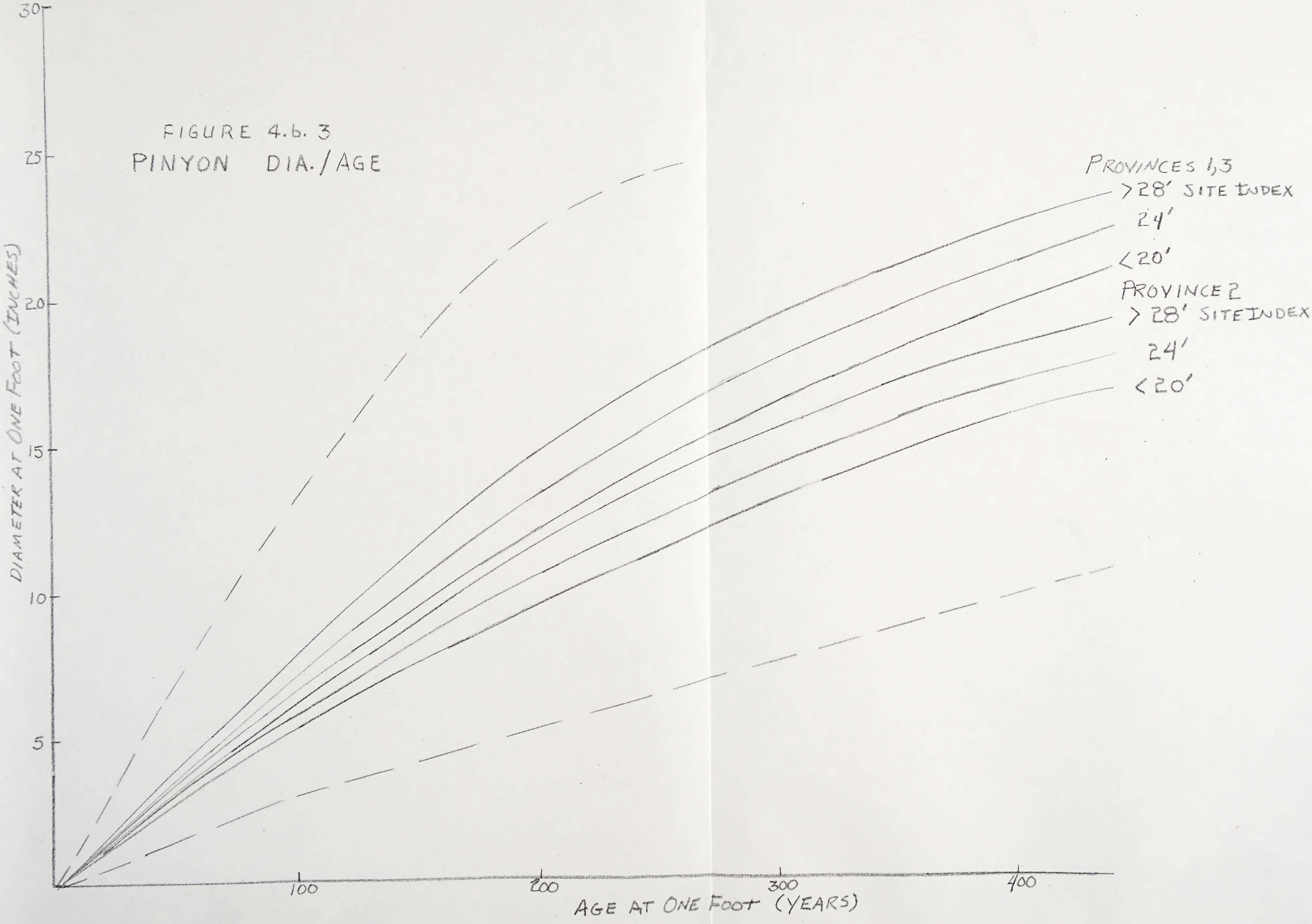


FIGURE 4.b. 3
PINYON DIA./AGE

HEIGHT FEET

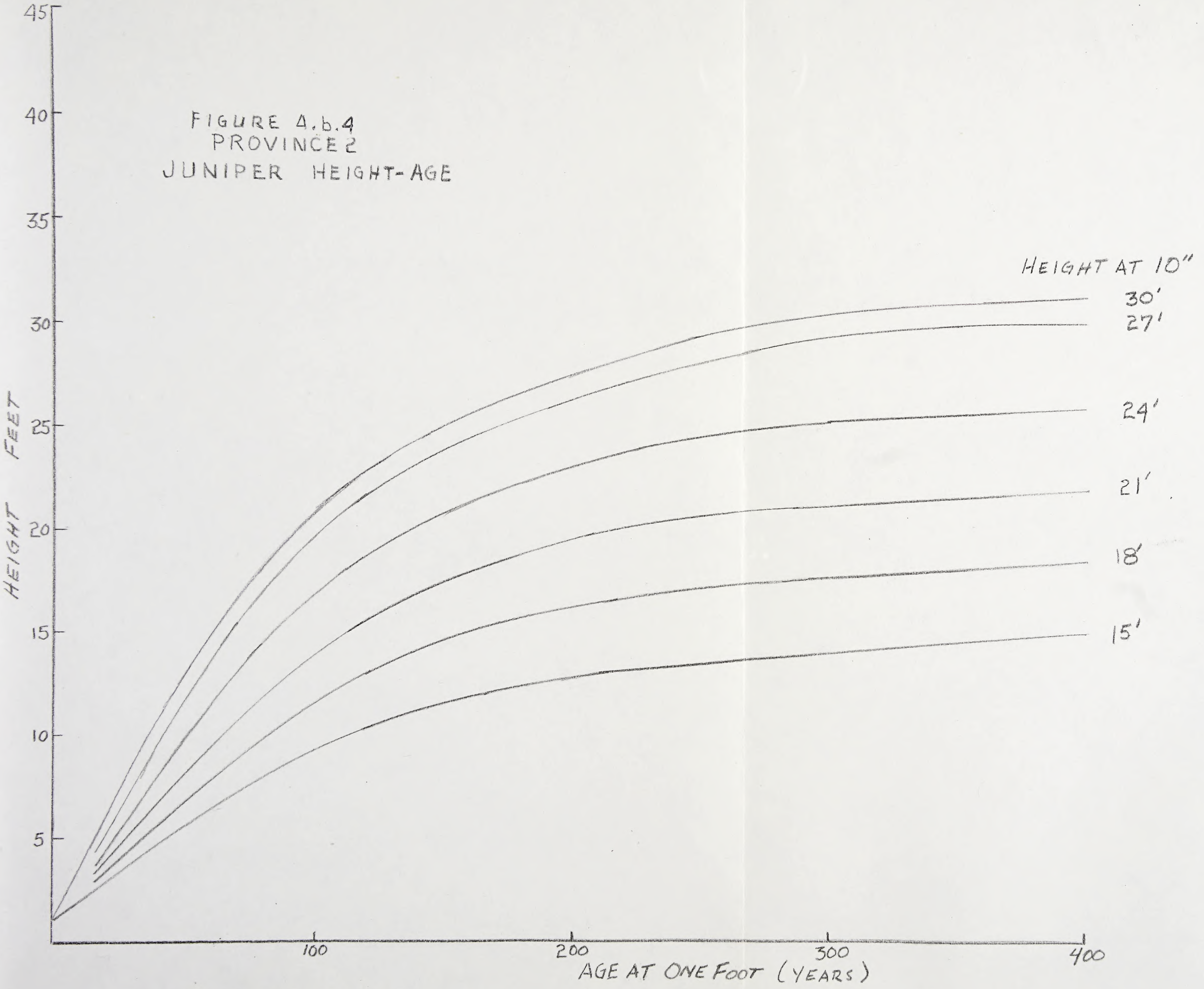


FIGURE 4.b.4
PROVINCE 2
JUNIPER HEIGHT-AGE

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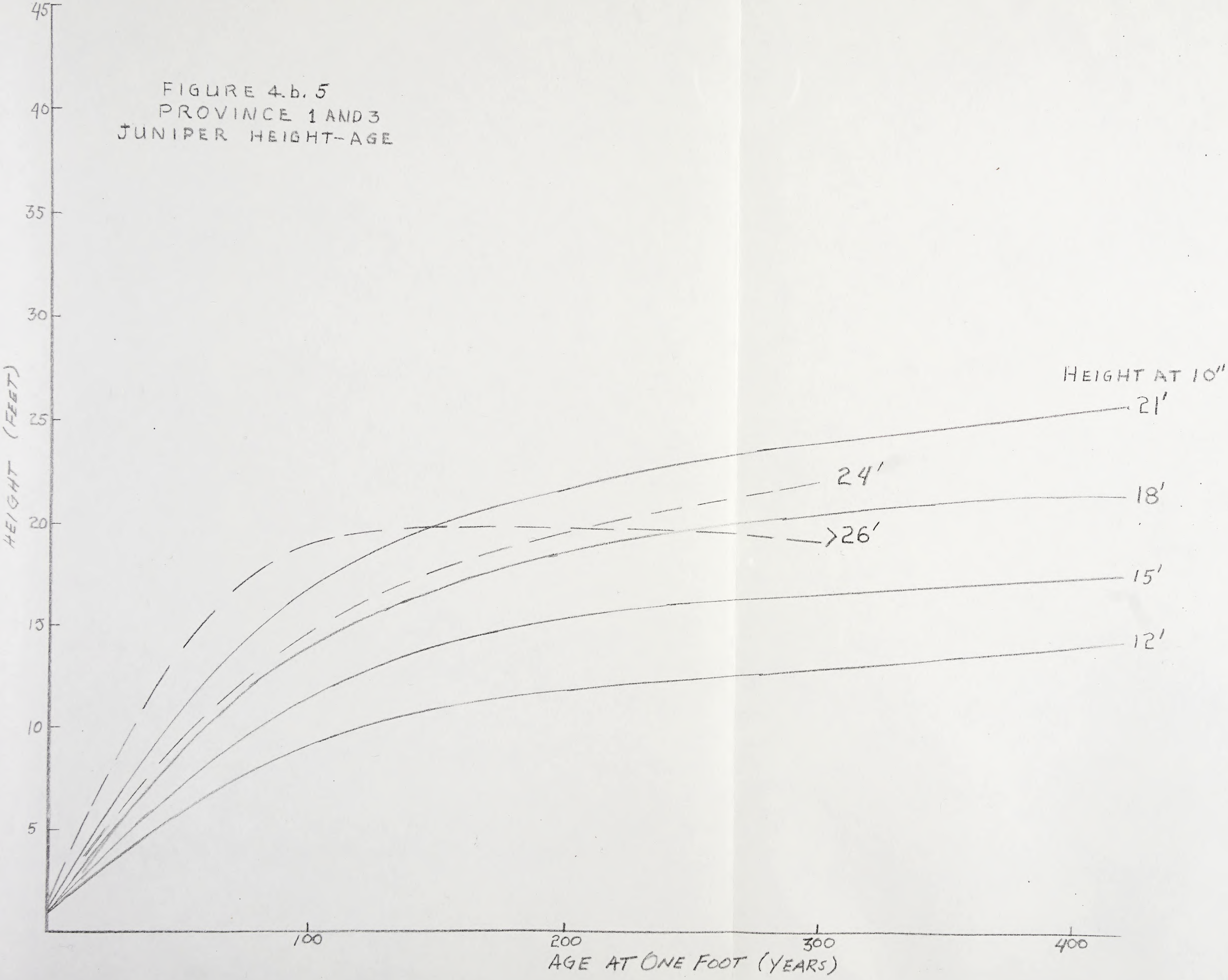


FIGURE 4.b.5
PROVINCE 1 AND 3
JUNIPER HEIGHT-AGE

DIAMETER AT ONE FOOT (INCHES)

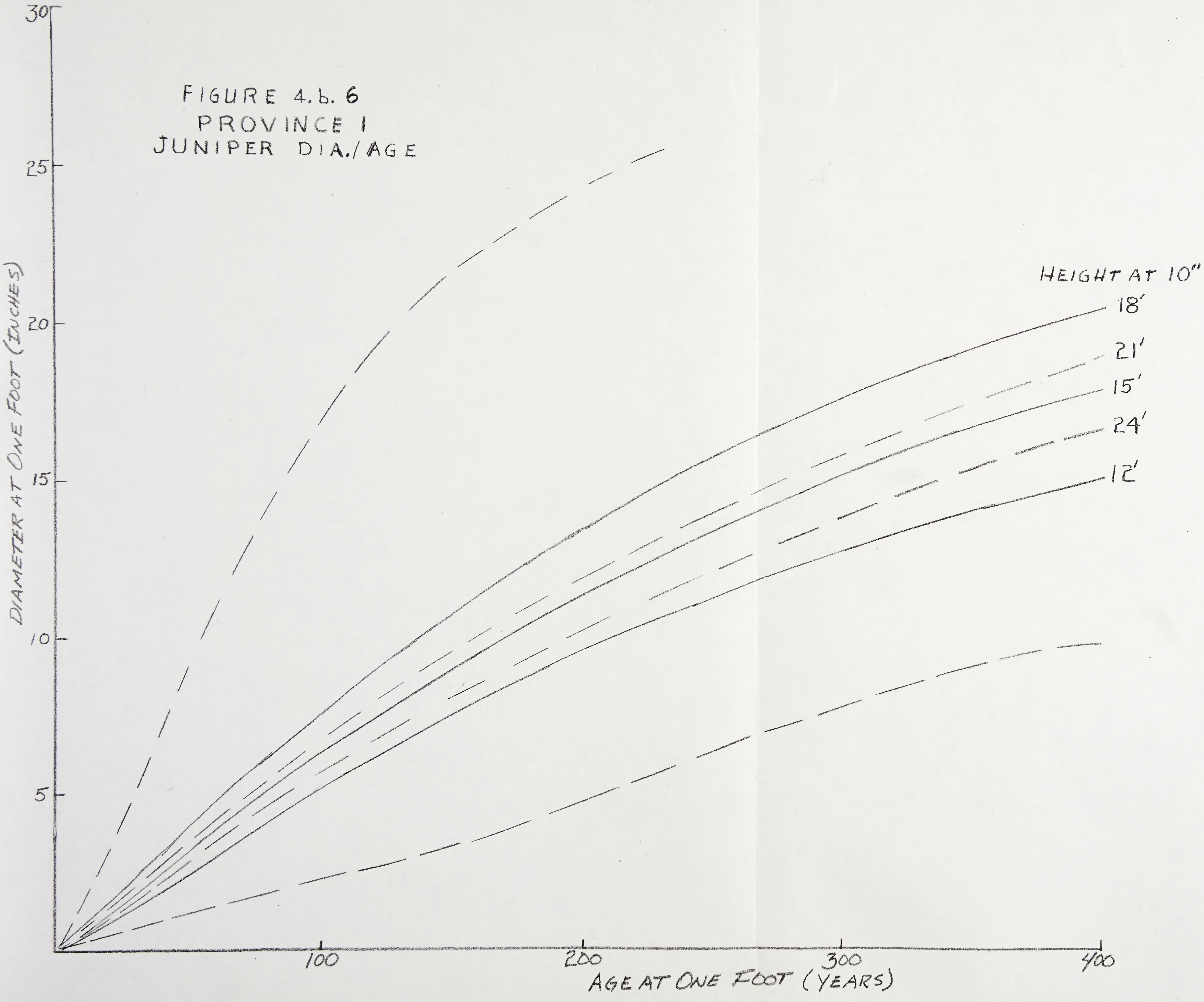
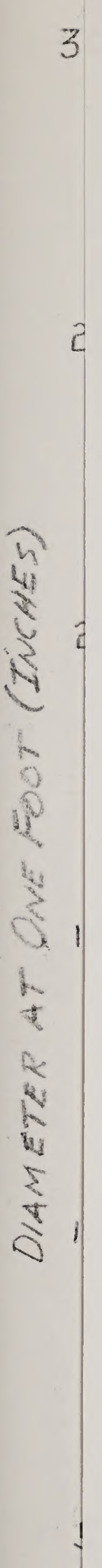


FIGURE 4.b.6
PROVINCE I
JUNIPER DIA./AGE


3
2
1
DIAMETER AT ONE FOOT (INCHES)

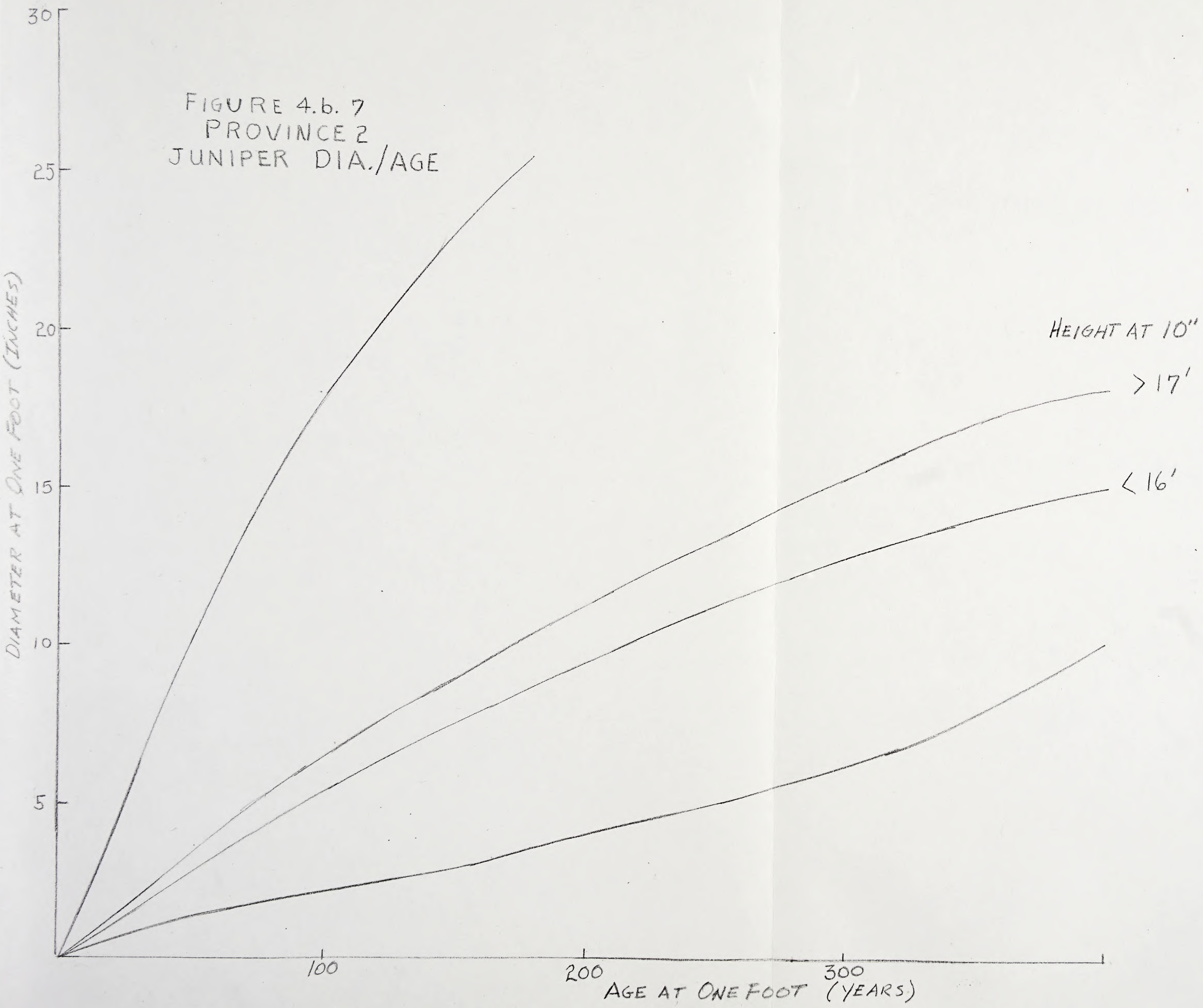


FIGURE 4.b. 7
PROVINCE 2
JUNIPER DIA./AGE

DIAMETER AT ONE FOOT (INCHES)

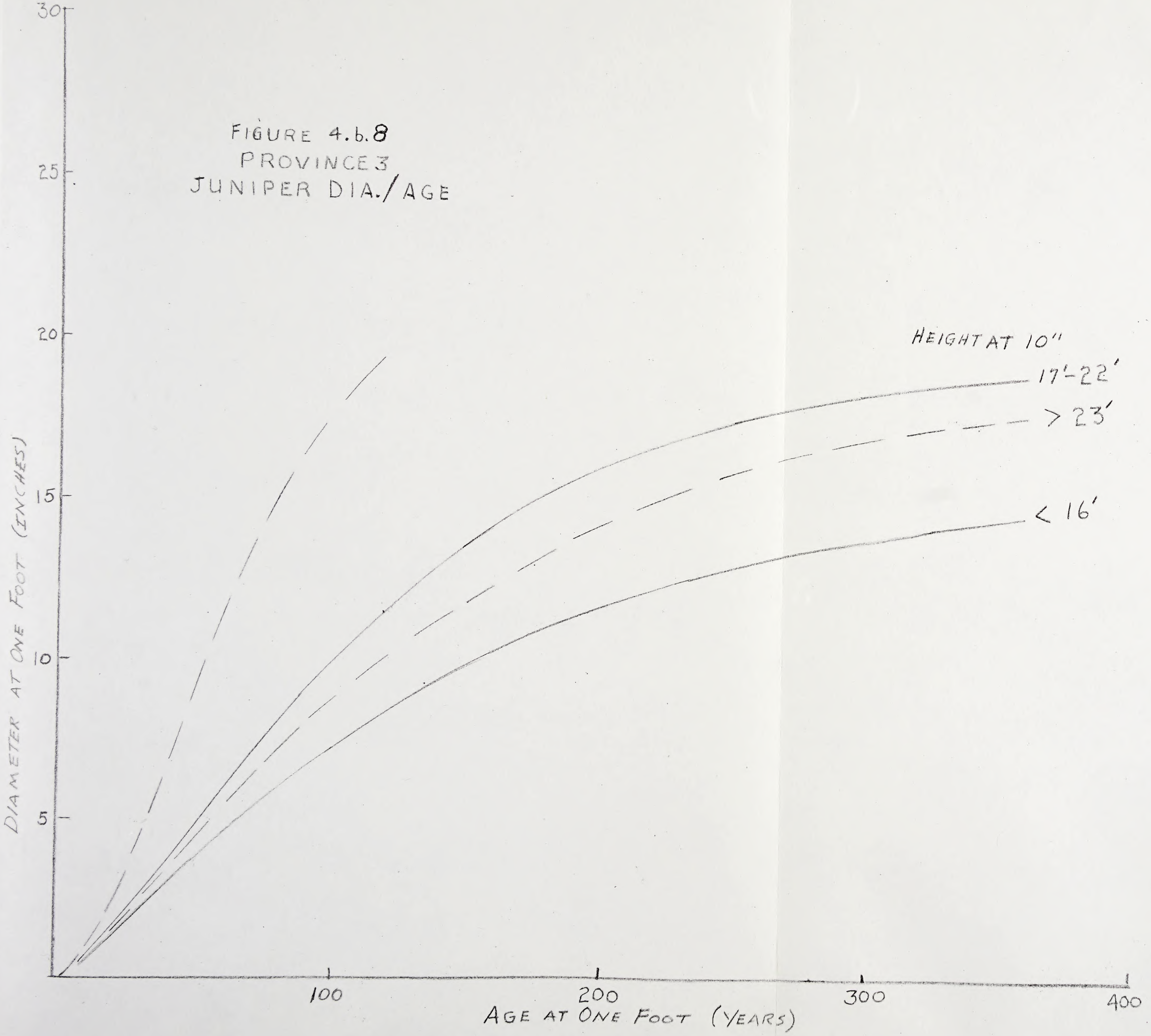


FIGURE 4.b.8
PROVINCE 3
JUNIPER DIA./AGE

volume (in cubic feet) and products (fence post) estimates for various crown diameter-tree height relationships [Moessner, 1962]. No attempt was made to stratify this material by site.

The possibilities of crown diameter-site interactions have been implied in several studies [Woodin and Lindsey, 1954; Weike, 1963; Liebold, 1963]. This possibility is also discussed by Spurr, who states that since tree height and crown diameter can be measured by aerial photos, it is possible that, under certain conditions, the ratio between tree height and crown diameter will provide a measure of site quality.

This section presents a consideration of Pinyon-Juniper height-crown diameter characteristics as related to site.

Definitions- i. Tree height: Total height from the ground level to the tip of the dominant stem. Measured to the nearest 0.1 of a foot.

ii. Crown diameter: Average width of the tree crown as determined from two diametrically opposite measurements from one extreme tip to the other.

iii. Site class: Based on the tree height at the 10" diameter class read from the height/diameter curve for that plot.

Site class	Ht. at 10" diameter class
1	24' - 31'
2	21' - 23'
3	18' - 20'
4	11' - 17'

iv. Basal area classes:

Class	B.A./acre
1	0-61 sq. ft.
2	61-∞ sq. ft.

Basic data- The data used in the preparation of the height-crown diameter curves were secured from 213 one-tenth acre plots located throughout the five state area.

All of these plots were established during the 1964 field season. The measurements were in addition to those used for collection of site index data. Tree measurements for the present study included total tree height (to the nearest one-tenth of a foot) and crown diameter (to the nearest foot).

Crown diameter measurements were summarized and the mean crown diameter obtained for each tree height class for both pinyon and juniper. These data were further stratified by basal area classes, site classes, and provinces. An analysis of variance was run to determine if any significant difference existed between the means when stratified by the basal area and site classes. A regression analysis provided the statistical equation for height-crown diameter relationships within each province and for all provinces combined.

Analysis and discussion- The results of the analysis of variance indicated that no significant difference existed when the data were stratified by basal area classes. There were differences when the data were arranged by sites or provinces.

Province differences were not strong in the pinyon data. It is more significant to stratify by site. Table 4.c.1 lists the site classes and linear regression parameters.

The juniper height-crown diameter correlation coefficients improved when the data were stratified by provinces and sites within a province. Table 4.c.2 lists by province and site class the results of the linear regression of juniper heights on crown diameters. Insufficient observations prevented stratification into three site classes per province. More data could increase the R^2 values if these provinces could have been broken down into three site classes.

The height-crown diameter correlations support the notion of definite site indices and confirms Spurr's statement noted above. It should be realized that the classifications amount to good-fair-poor sites for pinyon and good-poor sites for juniper.

Table 4.c.1. Pinyon Sp. ht./cr. diameter regression formulas

Site class	Regression equation	R^2	Ht. observations represented in analysis	Graph No.
All	y = 0.621 + 0.517 (X)	0.946	4'-42'	Not presented
21'-31'	y = 2.7159 + 1.6387 (X)	0.984	4'-40'	4.c.1
11'-20'	y = 1.1286 + 1.4308 (X)	0.935	4'-30'	4.c.1
24'-31'	y = 3.8006 + 1.5979 (X)	0.955	4'-40'	4.c.2
18'-23'	y = 1.2640 + 1.5804 (X)	0.969	4'-32'	4.c.2
11'-17'	y = 1.2879 + 1.2356 (X)	0.968	4'-24'	4.c.2

Table 4.c.2. Juniper Sp. height/crown diameter regression formulas

Site class	Province	Regression equation	Correlation coefficient	Ht. classes represented in analysis	Graph No.
All	All	y = 1.918 + 0.487 (X)	0.825	4'-33'	Not presented
All	1	y = 1.051 + 0.778 (X)	0.954	4'-24'	Not presented
21'-31'	1	y = 2.767 + 1.262 (X)	0.957	4'-28'	4.c.3
11'-20'	1	y = 1.874 + 1.163 (X)	0.991	4'-25'	4.c.3
All	2	y = 0.279 + 0.587 (X)	0.920	4'-24'	Not presented
21'-31'	2	y = 1.791 + 1.746 (X)	0.903	4'-24'	4.c.4
11'-20'	2	y = 0.371 + 1.307 (X)	0.946	4'-23'	4.c.4
All	3	y = 0.366 + 0.746 (X)	0.890	4'-24'	Not presented
21'-31'	3	y = 2.939 + 1.146 (X)	0.943	4'-24'	4.c.5
11'-20'	3	y = 2.074 + 0.907 (X)	0.929	4'-22'	4.c.5

Exhibits 4.c.1 through 4.c.5 graph the equations presented in the previous tables. The height classes represented in these exhibits have been extrapolated beyond the observations used in the regression analyses. This allows for any combination of height-crown diameter for a given site index. In all cases the greatest amount of variation was found in the upper height classes. This is probably what would be expected and this phenomenon has been recorded in growth studies of Utah junipers [Baker, 1950]. The same situation probably exists in both Pinus monophylla and Pinus edulis. The longevity (600 years) of these trees plus the adverse climatic conditions under which these species exist all explain a reduction or die-back in total height in overmature age classes.

Recommendation- In the event of future on-the-ground site evaluation, crown diameter-height relationships can be used as a cross check with tree height to make sure that the sample area is on the desired site class. This application of crown diameter association was used by Woodin and Lindsay in their study of P-J east of the Continental Divide [1954].

If suitable photos are available, it should now be possible to inventory P-J stands not only by height classes, but also by site indices. For this purpose, curves 4.c.1, 4.c.3, 4.c.4, and 4.c.5 should be used. These curves represent site indices divided into 10' height classes. During initial application of these data, some difficulty might be encountered since crown diameter measurements by photos are usually smaller than comparable ground measurements. The value of these data will depend on the skill of the photo interpreter and the quality of the photos being used.

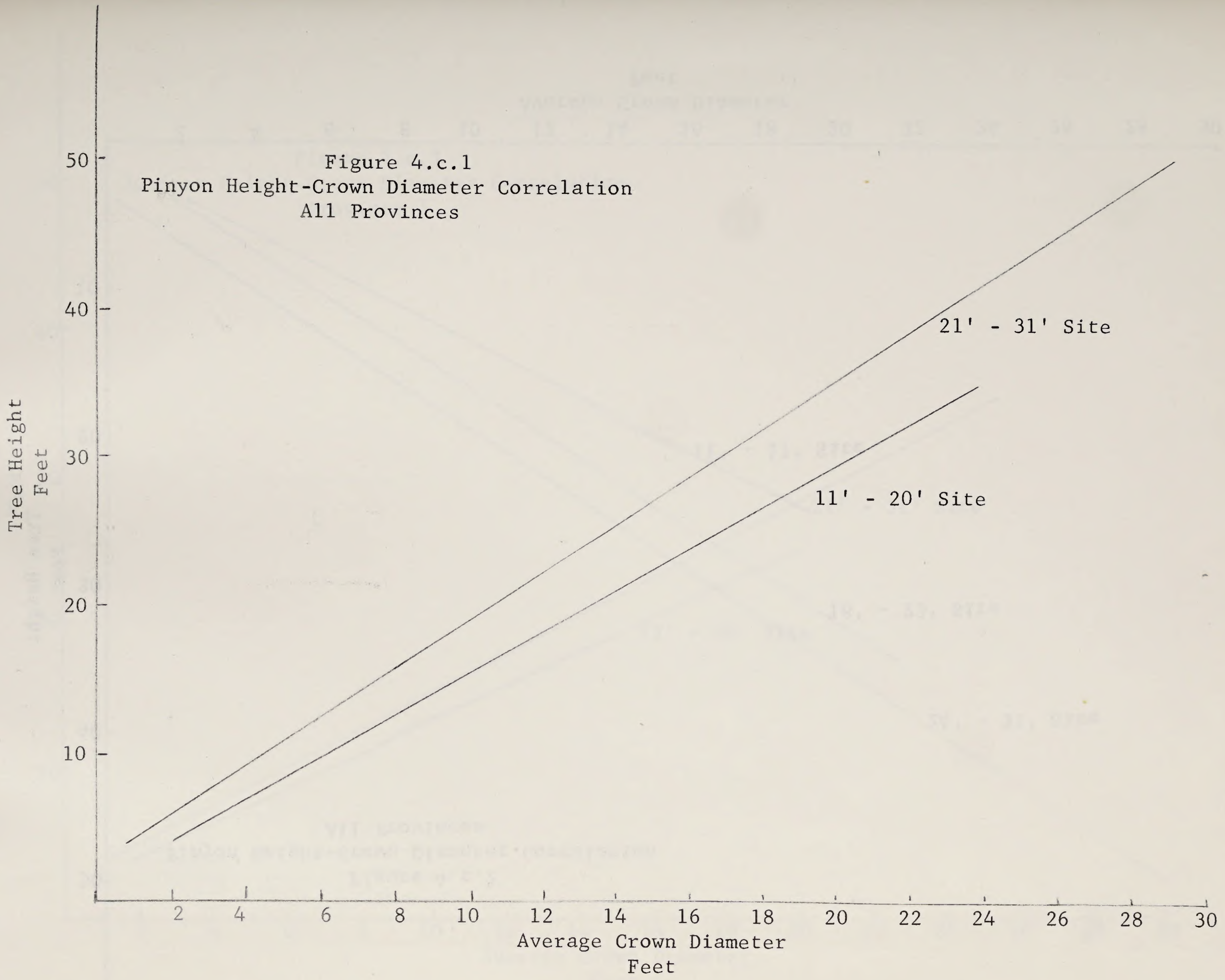


Figure 4.c.1
Pinyon Height-Crown Diameter Correlation
All Provinces

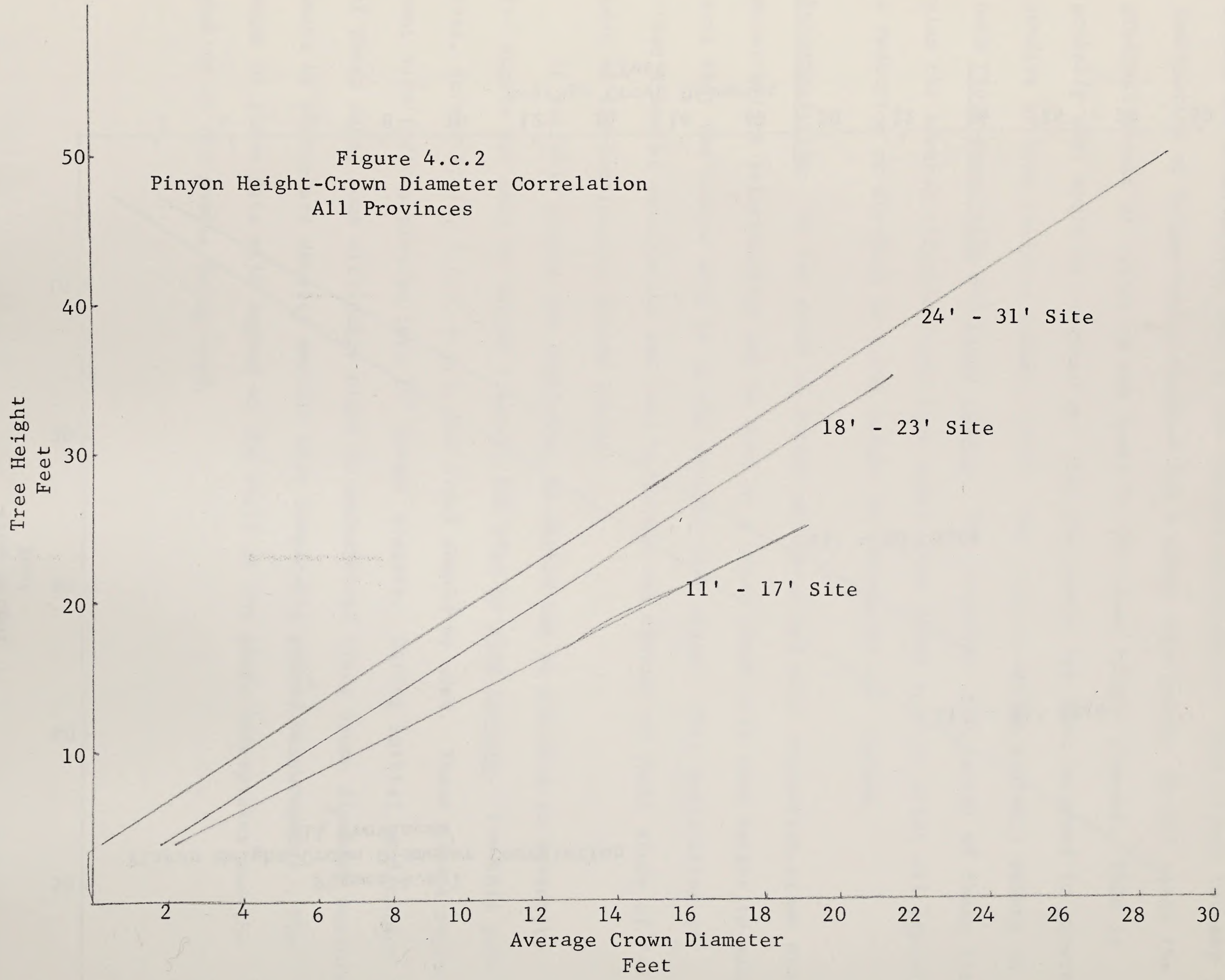


Figure 4.c.2
Pinyon Height-Crown Diameter Correlation
All Provinces

Figure 4.c.3
Juniper Height-Crown Diameter Correlation
Province 1

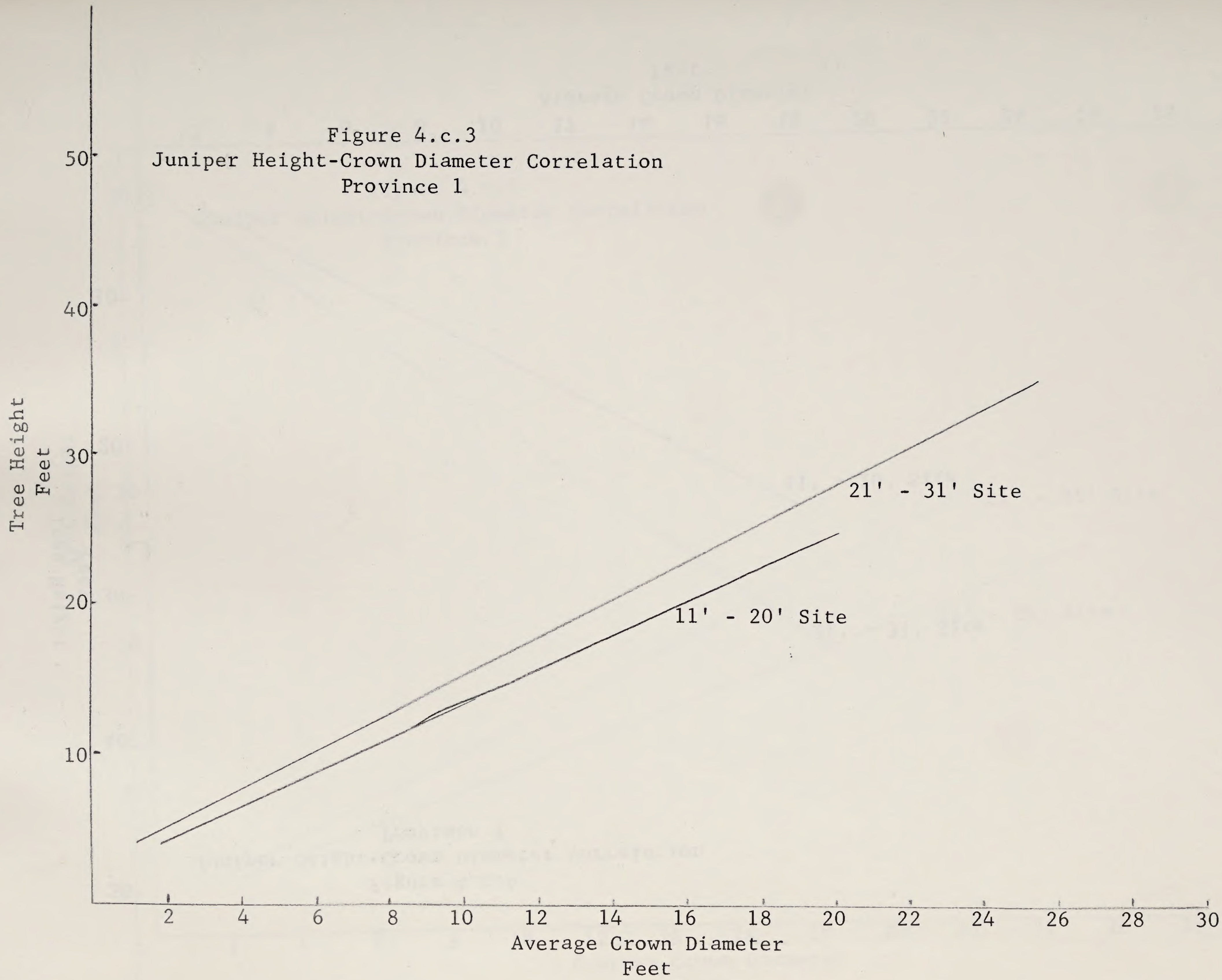
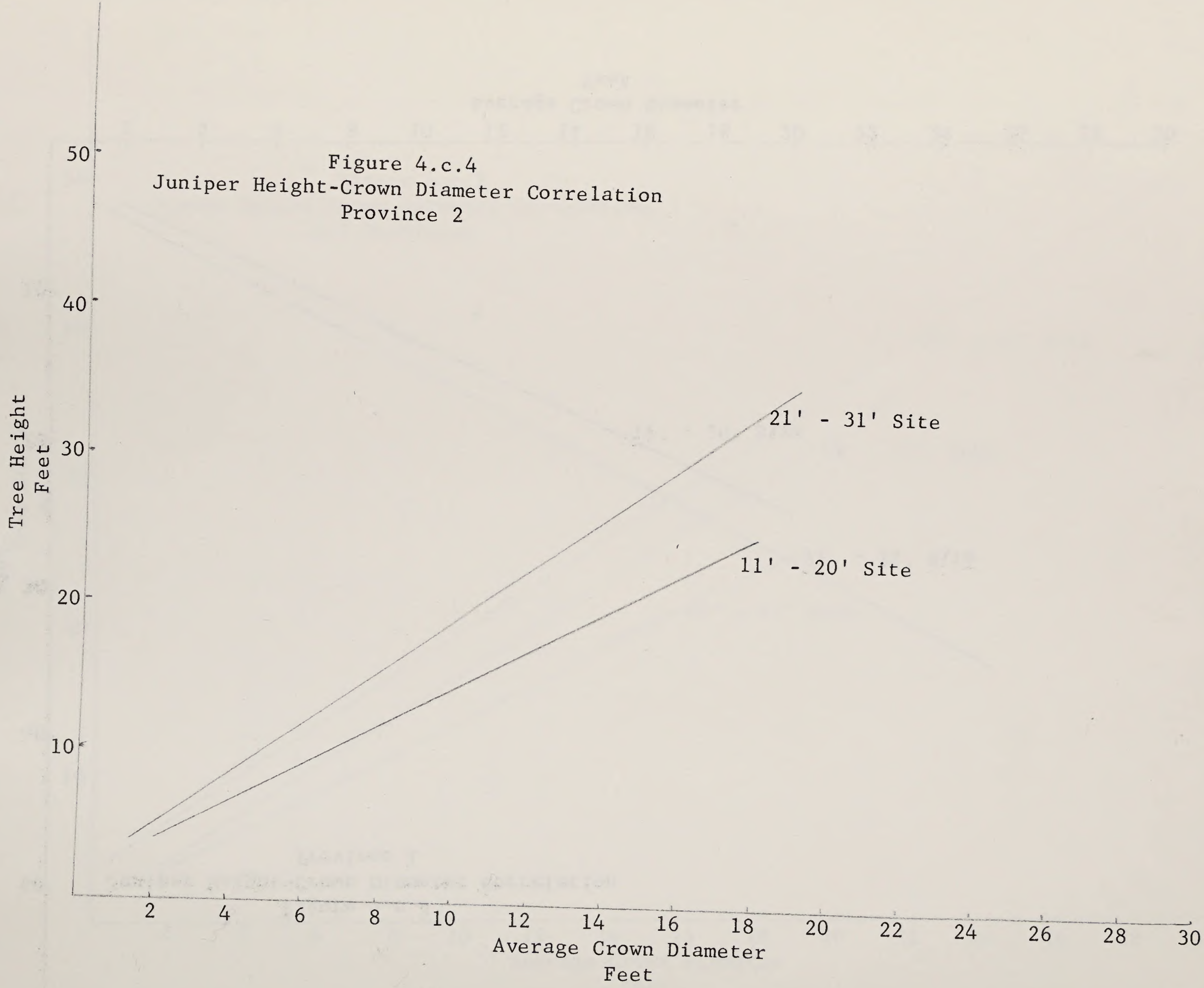


Figure 4.c.4
Juniper Height-Crown Diameter Correlation
Province 2



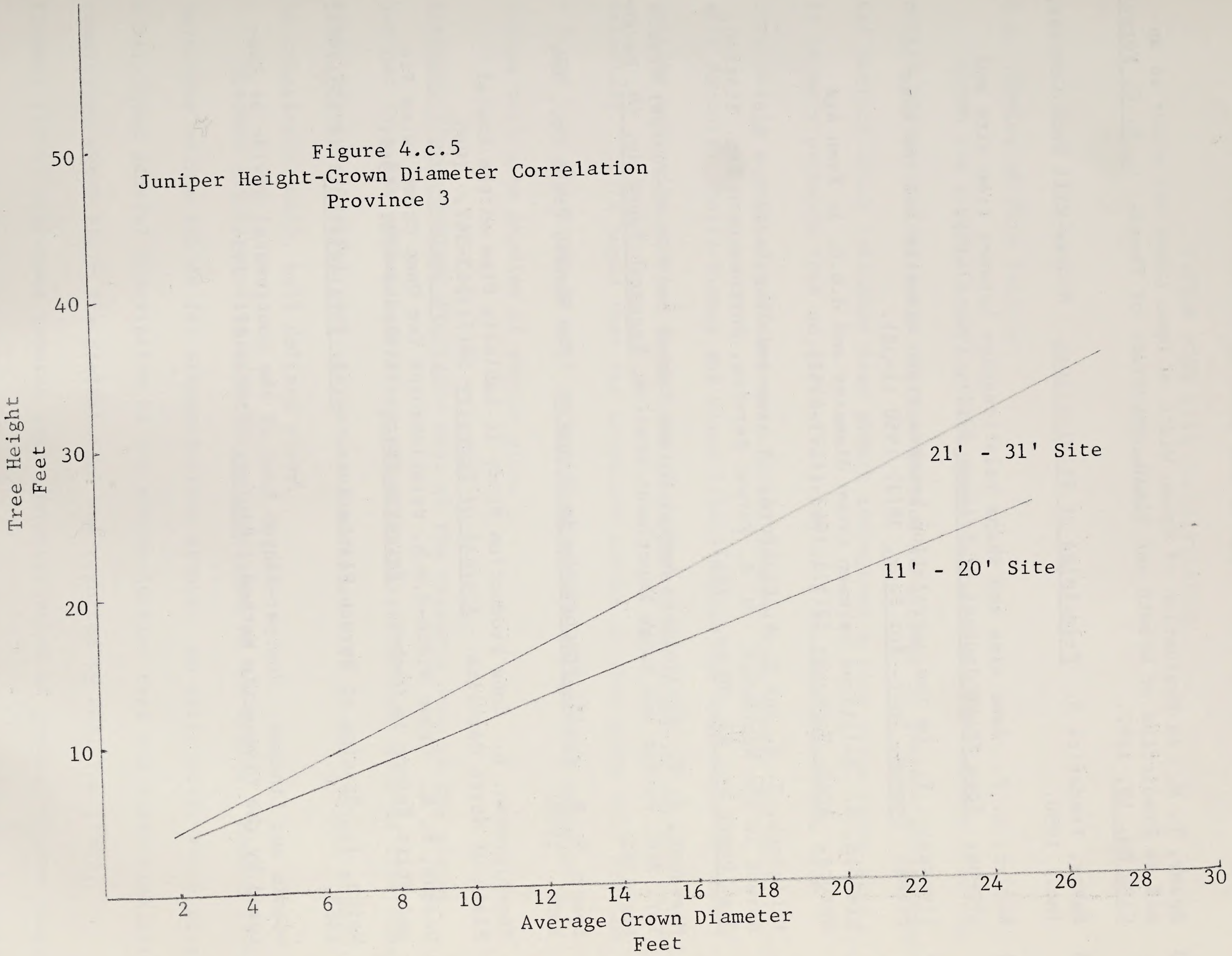


Figure 4.c.5
Juniper Height-Crown Diameter Correlation
Province 3

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5. RELATIONSHIP OF SOIL AND CLIMATIC FACTORS TO PINYON PINE SITE CLASSIFICATION

E. J. Eberhard

5.a. Choice of Site Factors

Given the present need for management and economic information over the entire pinyon-juniper range, it was decided to attempt to isolate environmental factors which influence tree growth throughout a five state study area. It is very probable that an intensive study of a smaller area would have resulted in a more significant correlation between tree growth and soil-site factors. Della-Bianca and Olson [1961] stress the importance of conducting soil-site studies on a local geographical basis and on uniform parent materials. It is hoped that the extensive nature of this study will provide a broad base which can be used in interpreting and integrating results of future soil-site studies of pinyon pine.

Previous Pinyon-Juniper Studies-- Most of the research done on the pinyon-juniper type has emphasized either economic considerations, such as tree control, or environmental characteristics associated with pinyon-juniper stand in relatively small, well defined areas.

Chapman [1918] studied growth rate of pinyon in New Mexico. Howell [1941] developed volume tables for pinyon-juniper stands. An early study which gives a very good general description of the pinyon-juniper type and identifies site conditions which limit its distribution was reported by Phillips [1909]. Plummer [1958] discusses general soil characteristics of juniper-pinyon ranges in Utah. Germination and establishment of pinyon-juniper as affected by shade and soil moisture was studied by Meagher [1943]. Randler [1949] and U.S.D.A. [1909] discuss general site characteristics of the pinyon-juniper type over its entire range. Dixon [1935], Tanner [1940], Reveal [1944], Merkle [1952], and Jameson _et al_. [1962] made comprehensive studies of localized pinyon-juniper areas. Woodin and Lindsay [1954] reported a phytosociological study of cover and density on pinyon-juniper east of the continental divide using the line-strip method. Little [1944] describes insects which attack pinyon pine, and Boyce [1961] discusses diseases of pinyon pine. Arnold _et al_.[1964] presents an excellent coverage of the effects of grazing, fire, and tree control on pinyon-juniper lands in Arizona.

Factors Considered in Other Soil-site Studies-- Jenny [1941] states that site factors are identical to the soil forming factors of climate, organisms, topography, parent material, and time. Major [1951] argued that these five soil-forming factors also defined the vegetative system. Jenny [1958] and [1961] supports this argument saying, in fact, that the five soil-forming factors define the state of the ecosystem. He calls them "state factors." Jenny [1941] has also stated that in most systems of soil classification, the time factor or degree of maturity plays the most important role. Since the time factor is difficult to measure, we can only measure soil properties which are dependent on time, and relate these properties to the development of vegetation.

Pawluk and Arneman [1961] found significant correlations between soil physical properties and site index, however, it was found that it was difficult to isolate the most limiting factor. In their study of soil characteristics in relation to tree growth, they imposed limits by equalizing external drainage, stand density, slope, aspect, and slope range because of the large number of other factors which could influence tree growth. Gardner and Lyford [1955], Kittredge [1938], and Turner [1937] treated the numerous soil characteristics as independent variables and established site quality classes on the basis of the soil as a whole. The importance of the influence of soil physical properties on tree growth has been stressed by Auten [1940], Locke [1941], and Plair [1952]. Zinke [1959] found that site index was not closely related to the present classification of soil series for Douglas-fir and ponderosa pine in northeastern California. Gardner [1958] states that natural vegetation is generally associated with soil series or higher soil groups, but that the amount of vegetation or the rate of growth is usually associated with intra-series differences. Some of the specific variables used in other soil-site studies and their value in this study will be discussed below.

Topography-- According to Klemmendson and Murray [1963], a brief review of the literature indicated that topography has been the site factor most frequently used in site quality studies. Jenny [1941] attributes this to the widespread appreciation of the influence of topography on disposition of rainfall and on soil formation. Tarrant [1950] found that significantly higher Douglas-fir site quality was associated with concave topography rather than convex topography. He suggests that soil surveys may require a measure of topographic conditions to supplement the fairly broad soil-mapping units now used. Klemmendson [1963] correlated several physical and chemical soil properties with slope position and aspect. Doolittle [1957] used slope position, aspect, and slope steepness as important factors in predicting site index of oak. Turner [1938] associated steepness of slope as one of the factors influencing site index of southern pine. Locke [1941] used aspect as one of three factors to predict timber yield. Carmean [1961] found that slope position, aspect, and steepness were among the variables that could be used to classify site quality of black oak. Myers and Van Deusen [1960] used slope position, steepness, and aspect as part of the variables for predicting site index of ponderosa pine in the Black Hills.

The influences of topography are complex and interrelated. Shreve [1922] discusses these relationships while explaining the vertical distribution of vegetation on desert mountains. Eis [1962] concludes that topography is the primary factor influencing soil and water conditions within a given macroclimatic region. The effect of topography on evaporation rate, amount and distribution of precipitation, infiltration, and surface runoff must be included in any soil-site study.

All possible topographic functions were measured during the course of the present study, but statistical analysis indicated that positioning plots on broad, gentle slopes cancelled out any site differences that might be due to topographic features. A substantial majority of the plots were located on slopes of from 4 to 7 percent where the effect of aspect and surface runoff was negligible. However, scatter diagrams using data from some of the steeper slopes showed that total precipitation, when modified by field estimates of surface run-off, was relatively less important in terms of tree growth.

Since one of the primary purposes of the study was to investigate alternate uses of pinyon-juniper lands, and only limited use can be made of steep and rough terrain, these areas were not sampled. It is very probable that these severe topographic features would have been highly correlated with site index of pinyon.

Climate-- According to Carmean [1954], Coile [1952], and Zinke [1959], foresters have made only limited use of precipitation data, and practically no use of temperature records to predict site quality, probably because of difficulties in obtaining reliable climatic data. They have preferred to measure influence of climate by variables which are dependent on precipitation. Carmean [1954] states that any soil property or site factor that regulates or is closely related to soil moisture or soil aeration may be expected to have a definite correlation with site quality. Landsberg [1961] points out factors which exert an influence on local climate.

Herman [1956] reports in a study of Arizona juniper that there is a close relationship between growth and rainfall within each season. He further points out that there is a primary growth period which uses stored moisture from winter precipitation. When this moisture is gone, growth stops but starts again with annual August rains. Temperature controls growth, when moisture is available, in both spring and fall.

Because of the regional nature of this study and the recent publication of isohyetal maps by the Water Supply Forecast Unit and Office of State Climatologist, U. S. Weather Bureau, in Salt Lake City, it was decided to include winter precipitation, summer precipitations, July-August precipitation, and total annual precipitation as part of the site data for each plot. In addition, information on evaporation was used from Meyers' [1962] publication to compute precipitation/evaporation ratios, and potential evaporation rates for each plot. As might be expected, most of these data were useful in predicting pinyon site quality.

Soil Depth-- Total soil depth is one of the most common and one of the most reliable site factors used in evaluating site quality according to Carmean [1954]. Deeper soil profiles have a higher productive capacity than shallow soils because of increased aeration and rooting space. Coile [1948], Myers and Van Deusen [1960], Carmean [1961], Zahner [1958], Turner [1938], Doolittle [1957], and Coile [1948] all used soil depth as one of the factors which was important in predicting site quality. Medin [1960] used soil depth as one of the site factors influencing annual production of true mountain mahogany.

Parent Material-- Many researchers, Carmean [1956], Myers and Van Deusen [1960], and Zinke [1958], have stratified soil site data into parent material groups and have found that parent material influences site quality considerably. Many investigators use texture as a soil property which expresses the influence of parent material [Doolittle, 1957].

Soil Aeration-- Depth of A horizon (or depth to low aeration) should be a reliable indicator of growth potential on heavy-textured, mature, or intrazonal soils likely to have compacted or cemented horizons that effectively restrict root growth [Coile, 1952; Garland et al., 1959; Kreis et al., 1956]. Kramer and Kozlowski [1960] state that in soils where diffusion of gases and movement of water is restricted by fine subsoils, compact horizons, or a high water table, a deficiency of oxygen may stop root growth.

Stand Density-- Shirley and Zehngraff [1942], working with red pine, and Turner [1943], working with southern pine species, noted greater tree heights in denser stands on similar sites. However, Mann [1952] found that for practical purposes, stand density can be ignored in estimating site index for slash pine. Baker [1953] found that the density of trees probably did not influence height growth of ponderosa pine on the same soil-site. It is probably safe to assume that the effect of density on tree height is the result of several interactions between density and other site factors. In the case of pinyon-juniper stands, Woodbury [1933] observed that on drier slopes, the trees are widely spaced and often stunted in size. He rationalized that those soil and geographic situations with greatest soil moisture usually produce the larger individuals and the denser stands.

Soil Moisture Relations-- According to Carmean [1954], Coile [1952], and Zahner [1958], any soil property that regulates or is closely related to soil moisture may be expected to have a definite correlation with site quality. White [1958] concludes that, " . . . most workable classification schemes are, in effect, an attempt to estimate indirectly the soil moisture regime and, specifically, available water for tree growth." Eis [1962] states that almost all the variability of the plant communities studied can be accounted for by differences in soil and moisture regime. These soil-water relations are the primary result of soil physical properties. Bassett [1964] and Campbell and Rich [1961] have developed rather complex systems of evaluating soil moisture and relating it to plant growth.

In the present study many of the variables used to predict site quality are indirect expressions of soil moisture conditions.

Texture-- Texture expresses a measurement of both parent material influences and soil moisture relations according to Wilde [1935]. Kittredge [1938], Turner [1938], Carmean [1961], and Doolittle [1957] have all used texture as one of the significant variables for predicting site quality of various tree species.

Lime-- Shantz [1923] correlated plant distribution with depth of the calcium carbonate layer below the surface. He stressed the important point that the depth to lime indicated the depth of soil periodically moistened by rainfall. Jenny and Leonard [1934] found an excellent relationship between depth to lime and rainfall in the uniform loesial prairie soils of Colorado and Kansas. However, this study points out the fact that if depth to lime is to be a reliable indicator of site quality, then differences in parent material, texture, and soil depth must be considered.

Methods-- Field procedures used in gathering soil-site data are explained in Section 2.c of this report. Data were taken in essentially the same manner during each of the two field seasons.

The 212 plots taken the first field season were analyzed somewhat differently than were the 351 plots selected for final study. The specific variables used, the results of the 1964 analysis, and the analysis of the 1964-65 total of 351 plots will be reported separately.

1964 Plots-- Using soils and climatic data collected from 212 tree sites, the following variables were used in an attempt to predict pinyon pine site quality.

a. Elevation -

b. Percent Slope -

c. Ecological orientation - This is = (Azimuth - 45°), making 315" azimuth read as 0° ecological orientation to go from a mesic to a xeric site with increasing numbers.

d. Slope character -

e. Slope position -

f. Surface runoff - This is recorded as ranging from 25 → 0, with increasing runoff with decreasing numbers. Based on field estimates.

g. Soil stability - Recorded as decreasing stability from 25 → 0, with decreasing numbers. Taken from field estimates.

h. Average profile composition - The following textures were given numbers from 1 → 9, increasing with increasingly heavy soils:

Gravel	1
Sand	2
Sandy loam	3
Loam	4
Silt loam	5
Silt	6
Clay loam	7
Silty clay loam	8
Clay	9

i. Calculated available moisture of profile - The average profile composition was compared to a "soil texture-moisture avail" curve prepared from information found in Soil Survey Manual. The available moisture per foot of profile is taken from this curve and multiplied by the number of feet in the profile.

j. Field estimate of moisture holding capacity - for 60" soil. Estimated in the field.

k. Soil permeability -

Classes	Rate
Slow	0.05 - 0.20
Moderate	0.20 - 5.0
Fast	5.0 - 10.0+

Classes assigned were taken from field sheets with rapid and very rapid categories combined. Structure, consistence, and plasticity are involved in this determination.

l. Surface texture - This was recorded with reference to increasing weight in the surface horizon from 1 → 9 using the values previously assigned.

m. Rock on surface -

n. Rock in upper profile -

o. Rock in lower profile -

These were rated from 1 → 5, with increasing rock represented by decreasing numbers, as follows: Percent of rocks were those 2 mm and larger.

1 - 60% + rock
2 - 30-60 "
3 - 10-30 "
4 - 0 -10 "
5 - 0% rock

p. Depth to clay layer - Depth measured to nearest inch from soil surface to first clay textured horizon as:

Silty clay
Sandy clay
Clay

In soils having no clay, this depth is recorded as the depth to bedrock.

q. Total root depth - Root depth to nearest inch as closely as could be determined from data available on field sheets.

r. Depth of profile - Total depth, to nearest inch, by shovel or by auger. Dependence of roots on fractures in bedrock - rated from 1 → 5 as follows:

Extremely dependent - 1
Highly dependent - 2
Moderately dependent - 3
Light dependence - 4
No dependence - 5

s. Low aeration depth - Depth measured from surface to either a heavy clay horizon, cemented horizon, or consolidated bedrock.

t. Depth of soil below low aeration - The depth of soil between the top of the low aeration zone and bedrock materials.

u. Material underlying low aeration zone -

Underlying materials	"C" horizon code	Bedrock code
Eolian sand	1	
Loess	2	

Underlying materials	"C" horizon code	Bedrock code
Fine alluvium	3	
Coarse alluvium	4	
Tertiary sediments	5	
Lacustrine material	6	
Decomposing bedrock	7	
Bedrock	8	
Sandstone		1
Limestone/dolomite		2
Basic igneous		3
Shale		4
Metamorphic rock		5
Acid igneous		6
Undifferentiated material		7
Material continuous from "C" horizon		8

Nature of Bedrock	Code
Fractured	1
Consolidated	2
Unknown	3

v. Soil lime above low aeration depth and soil lime below low aeration depth -

w. PH @ Surface of profile (determined for uppermost horizon), pH immediately above low aeration - (determined for horizon immediately overlaying horizon containing low aeration zone), pH below low aeration (determined as the highest pH measured for the horizons between the low aeration layer and bedrock. If there was no low aeration zone, the pH used was the same as determined for the pH immediately above the low aeration zone.)

x. Profile normality - A profile was considered normal when soil texture became heavier in texture with depth.

y. Color of surface soil and color of upper profile -

1964-65 Plots-- After considering the results obtained from analyzing the soil-site data from the 1964 plots, a decision was made to continue using only the most significant factors. Some additional variables were added in an attempt to improve reliability. The final list was as follows:

a. Stand density - Where very dense stands were rated (1) and very open stands were rated (9).

b. Evaporation rate - Evaporation rate for each site from U.S.G.S. Prof. Paper 272-D.

c. Total precipitation/evaporation rate -

d. Depth to low aeration -

e. Profile depth -

f. Moisture holding capacity - Field estimate

g. Dependency of roots on bedrock - Rated (1) to (9) on the following basis: (1) Bedrock highly fractured, large and medium roots observed going into fractures; (2) to (4) Bedrock fractured, small or medium roots present in fractures; (5) to (6) Bedrock is not highly fractured, very few roots observed in fractures; (7) to (8) Bedrock appears to be infractured and/or is well below root zone; (9) Bedrock deeper than 60" or absent.

h. Percent rock in profile - Percentage of the soil volume occupied by rock in that portion of the profile not considered bedrock which may have some effect on tree growth and water relationships within the soil.

i. Depth to change in total soluble salt concentration - Profiles where no difference is noted or where TSS figures are higher in upper horizons are rated 0.

j. Average TSS - Weighted average of TSS concentration in that portion of profile above the highest concentration of TSS.

k. Highest TSS - Value which expresses the highest TSS concentration found in each soil profile.

l. Lime - present or absent.

m. Depth to sharp change in lime concentration -

n. Texture - Weighted average texture class estimated for the root zone of each profile. Gravel and coarse sand were considered as part of this textural classification. Ratings were from (1) to (8), with the smaller numbers designating the lighter textured soils.

o. Total precipitation -

p. Summer precipitation -

q. Winter precipitation -

r. Profile development - Rated from 1 to 5 based on presence or absence and the degree of development of the B horizon.

s. Elevation -

t. Latitude -

u. Longitude -

v. Total basal area per acre (tree stems) -

w. Province - 1. Escalante-Sevier; 2. La Sal; 3. Coronado.

x. Total average July and August precipitation - From Weather Bureau summaries for stations located nearest to each plot.

5.b. Statistical Analysis of Soil Plot and Climatic Data of 1964/1965 Plots

E. J. Eberhard and A. LeBaron

A "step-wise" regression analysis was performed using pinyon height at 10", D.B.H. as the dependent variable and 33 selected soil and site characteristics as independent variables.[1] The 212 plots were located within pinyon-juniper stands throughout the five state study area. No attempt was made to stratify the data by recognizable geographical, climatic, or edaphic characteristics. All data were from 1964 field sheets.

The model chosen assumes that all relationships are linear. In addition, the possible effect of interaction between the independent variables was not considered. A coefficient of determination (R^2) of 0.587 was obtained using all 33 variables. The results are summarized in Table 5.b.1. The variables are listed from top to bottom in the order that they dropped from the predictive model. The variables of the bottom of the list are the most significant in explaining variation in pinyon site quality. The last 8 variables in the list, winter precipitation, dependency of roots on bedrock, surface runoff, depth of profile, depth of soil below aeration, depth below aeration, total depth, and summer precipitation explain 41 percent of the variation in pinyon site quality.

Table 5.b.2 shows "f" values and regression coefficients (β) for the eight residual variables. The estimating equation is summarized at the bottom of the table. It will be noted that the "f" test values show all variables except one, to be significant at the 0.01 level.

1964-1965 Plots-- The data from all the tree sites sampled during the course of the study were stratified into three ecological provinces. The basis for

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[1] For description of the computer program, see Section 7.d.

Table 5.b.1. Step-wise regression analysis of 1964 plots

Variable	X_i	Coefficient of determination R^2
Ecological orientation	X_6	0.587
Profile normality	X_{31}	0.586
Lime-above	X_{26}	0.585
Profile composition	X_{11}	0.581
Color - upper	X_{33}	0.579
Lime - below	X_{27}	0.574
Rocks - upper	X_{17}	0.573
pH - surface	X_{28}	0.571
Rocks - lower	X_{18}	0.564
Calculated available moisture	X_{12}	0.561
Depth to clay	X_{19}	0.552
Soil stability	X_{10}	0.551
Percent slope	X_5	0.550
Slope character	X_7	0.547
Elevation	X_4	0.543
Surface texture	X_{15}	0.542
Permeability	X_{14}	0.542
Slope position	X_8	0.516
Rocks - surface	X_{16}	0.510
Material - below surface	X_{25}	0.501
pH - below	X_{30}	0.496
pH - above	X_{29}	0.484
Color - surface	X_{32}	0.465
Moisture holding capacity (est.)	X_{13}	0.465
Total precipitation	X_1	0.443
Winter precipitation	X_3	0.413*
Dependency on bedrock fracture	X_{22}	0.360*
Surface runoff	X_9	0.336*
Profile depth	X_{21}	0.304*
Depth - below low aeration	X_{24}	0.220*
Depth to low aeration	X_{23}	0.217*
Total root depth	X_{20}	0.201*
Summer precipitation	X_2	0.093*

*These variables explain 41 percent of the variation in pinyon site quality.

Table 5.b.2. Summary - residual variables, 1964 plots

Residual variable name and number	(R^2 = 41.3%) "f" value	β
Winter precipitation (3)	13.68	0.526**
Dependency on bedrock fractures (22)	6.86	-0.627**
Surface runoff (9)	6.26	0.200*
Profile depth (21)	25.64	0.443**
Depth - below low aeration (24)	24.86	-0.445**
Depth to low aeration (23)	28.45	-0.495**
Total root depth (20)	21.00	0.165**
Summer precipitation (2)	7.98	0.484**

Estimating equation:

$$y_1 = 10.41 + 0.526\ x_3 - 0.627\ x_{22} + 0.200\ x_9 + 0.443\ x_{21} - 0.445\ x_{24} - 0.495\ x_{23} + 0.165\ x_{20} + 0.484\ x_2$$

**Significant at 0.01 level.
*Significant at 0.05 level.

developing these provinces is discussed in Section 3.b of this report. A stepwise regression analysis identical to that performed on the 1964 plots was made with the tree site data for each province.

The number of independent variables was reduced to 22 for this analysis and somewhat better results were obtained than with the more general 1964 model.

When all the variables were included, they explained 61.2 percent of the variation in site quality within the Escalante-Sevier province, 53.1 percent of the variation in site quality within the La Sal province, and 64.7 percent of the variation in site within the Coronado province.

A model composed of "residual" variables was chosen to provide an estimating equation for each province. The set of residual variables differed in every instance. Summaries of the results from each province are reported in Tables 5.b.3, 5.b.4, and 5.b.5.

Table 5.b.3. Summary - residual variables, Escalante-Sevier province, 1964-65 plots ($R^2 = 49.3\%$)

Variable name and number	"f" value	β
Longitude (22)	4.79	0.057*
Depth to low aeration (9)	7.97	-0.124**
Precipitation/evaporation (8)	12.48	0.243**
Evaporation (7)	10.26	0.265**
Depth to change in lime (18)	15.07	0.128**
Lime-present or absent (17)	8.66	2.652**
Stand density (6)	21.32	-0.923**

Estimating equation: $\hat{y}_1 = 0.655 + 0.057\ X_{22} - 0.124\ X_9 + 0.243\ X_8 + 0.265\ X_7 + 0.128\ X_{18} + 2.652\ X_{17} - 0.923\ X_6$

**Significant at 0.01 level.
*Significant at 0.05 level.

Table 5.b.4. Summary - residual variables, La Sal province, 1964-65 plots ($R^2 = 45.3\%$)

Variable name and number	"f" value	β
Depth to low aeration (9)	6.47	0.062*
Precipitation/evaporation (8)	13.15	0.142**
Latitude (25)	11.01	-1.610**
Moisture holding capacity (11)	15.28	-0.989**
Stand density (6)	16.52	-0.685**

Estimating equation: $\hat{y}_1 = 27.329 + 0.062\ X_9 + 0.142\ X_8 - 1.61\ X_{25} - 0.989\ X_{11} - 0.685\ X_6$

**Significant at 1.01 level.
*Significant at 0.05 level.

Table 5.b.5. Summary - residual variables, Coronado Province, 1964-65 plots (R^2 = 54.9%)

Variable name and number	"f" value	β
Profile depth (10)	6.66	0.048*
Stand density (6)	17.08	-0.902**
Total precipitation (20)	15.67	0.523**
Basal area (23)	10.99	0.029*
Profile development (19)	18.44	-1.250

Estimating equation: $\hat{y}_1 = 20.73 + 0.048\ X_{10} - 0.902\ X_6 + 0.523\ X_{20} + 0.029\ X_{23} - 1.250\ X_{19}$

**Significant at 0.01 level.
*Significant at 0.05 level.

Discussion and Analysis-- In order to isolate highly significant site factors in a study of this kind, it is necessary to explore the various factor interactions which are thought to influence the soil-moisture regime and other important growth controlling systems. An analysis such as that reported by Hurst and Pederson [1964] conceivably could yield excellent coefficients of determination. But unless one is willing to experiment with a range of values for every element of each introduced interaction term, the points at which the interrelationships become critical remain a mystery. Any attempt to use an estimating equation involving such terms may be dangerous; prediction of site-quality in a particular instance might involve values of interaction elements that would result in negative height estimates, etc. Such cases require estimating equation adjustments based on knowledge of interaction term operations and some developed theories of the interactions themselves. This latter point is important. Unless such theories or hypotheses exist, and are defensible, it is difficult to make any statement about what is or is not being explained.

Nevertheless, some guesses were made concerning possible interaction terms and these were introduced as additional variables. The soil and site data were then run through the same "step-wise" regression program (but on a larger computer). No worthwhile improvements in coefficients of determination were obtained. Given the time and effort that would have been necessary to hypothesize and refine more sophisticated interactions, it was decided to rely upon only the linear model discussed above.

The results of that model are plausible, and since the estimating equations for each province (supra) imply somewhat simpler relationships than those reported in Section 7.d (in connection with grass yield), there may be some temptation to place too much faith in them. Fieldmen and administrators would realize that the cross-sectional site data undoubtedly exhibit multicolinearity and if certain critical (but unsuspected) values for site variables are introduced, the results will be unreliable. At the same time, it should be recognized that the relationships featured in the present study should provide definite insights for future soil-site research on pinyon pine.

a. Escalante-Sevier - Eight variables explain 49.3 percent of the variation in site quality. These variables in ascending order of importance are: longitude, depth to low aeration, precipitation/evaporation, evaporation, depth to change in lime, lime-present or absent, and stand density.

As the value for longitude increases from east to west, the site quality appears to go up. There is a possibility that the pattern of sampling location may have produced this result. As the depth to low aeration increased, the tree site quality decreased. The implications to this are not clear. The analysis indicated that as precipitation/evaporation ratio and evaporation rates increase, site quality should increase. Depth to change in lime is an indirect measure of the effectiveness of precipitation. Since the soils in this province are usually gravelly in texture, the positive relationship between an increase in the depth to lime, and an increase in site quality is probably valid. Absence of lime in the profile seems to indicate a higher site quality. This conclusion should be received with serious reservations until further studies are made. Stand density, which increases with an increase in site quality, is a valid expression of several soil and climatic interactions.

b. La Sal Province - Five variables explain 45.3 percent of the variation in tree site quality. These variables in ascending order to importance are: depth to low aeration, precipitation/evaporation, latitude, moisture holding capacity, and stand density.

With an increase in the depth to low aeration, tree site quality improves. This relationship appears to be valid considering the variation in soil textures throughout the province. As the precipitation/evaporation ratio increased, the site quality increased. This result indicates that rainfall is more effective in areas of low potential evaporation. This same relationship is reflected in the latitude variable, because potential evaporation rates are lower at the northern end of the province. As in the Escalante-Sevier Province, stand density is highly correlated with site quality.

c. Coronado Province - Five variables explain 54.9 percent of the variation in site quality. These variables in ascending order of importance are: profile depth, stand density, total precipitation, basal area, and profile development.

As depth of profile increased, site quality increased. As in the other two provinces, an increase in stand density indicated an increase in site quality. Basal area, which is a property of density, also increases on the better sites. The Coronado province, because of its geographical location, probably has a longer annual growing season than the other provinces. For this reason, it is safe to assume that total precipitation and profile development, which are functions of precipitation, are useful variables in predicting site quality (because moisture can be utilized during a longer period throughout the year).

5.c. Chemical Properties and Site Productivity--E. J. Eberhard

A representative sample of each horizon in the soil profiles described during the course of the study was collected for laboratory analysis. Because of the large number of samples involved, and the obvious limitations of time and money, it was not possible to examine all the chemical properties of the soil which might have proven useful in predicting potential site productivity of pinyon-juniper lands.

Almost all of the research reported in this section shows negative results. Statistical analysis of the data has not treated every possibility. This must be borne in mind when evaluating possible interactions between soil chemical factors and soil physical factors as well as the contention regarding negative results. It is assumed that the information reported here will be of value in future studies.

Effect of Other Site Factors on Chemical Properties-- There are several variables which cannot be accurately treated in terms of their possible effects on the relation of soil chemical properties and site productiveness. Probably the most important are differences in parent material. Della-Bianca and Olson [1961] stress the importance of conducting soil-site studies on a local geographical basis and on uniform parent materials. Many researchers [Carmean, 1956; Myers and Van Deusen, 1960; Zinke, 1959] have stratified soil-site data into parent material groups and have found that parent material exercises considerable influence on site quality. Lutz [1958] points out differences within parent materials. In most studies, differences in site quality attributed to parent material, are linked to differences in soil depth and texture rather than chemical differences. However, Forristall and Gessel [1955] and Youngberg and Scholz [1949] have placed emphasis on the importance of soil chemical properties to tree growth. Texture of a soil profile has a pronounced effect on chemical properties. The texture determines to a large degree the leaching and soil development that will take place in a given soil profile. It is quite possible that small textural differences could result in significant chemical differences between two profiles which have been classified as being similar in texture.

Adequate sampling is difficult. It is common knowledge that the chemical state of soil is dynamic, and that significant differences exist among soil samples taken in the same immediate area. Certainly this possibility should be considered in the present study where it has been necessary to represent an entire tree or grass site with a single soil sample. (The effect on vegetation of differences in chemical properties will be discussed later in this section.)

It is also recognized by most soil scientists that present laboratory procedures and the results obtained do not always reveal key variables in soil-chemical relationships [Millar, 1955]. Probably the best example of this situation is in determination of available nitrogen for crop growth.

In an extensive study such as this, there must be many other site factors which would exert a confounding influence on the utilization of chemical properties of soil for predicting site productivity. However, there is evidence that the use of both physical and chemical soil factors in an intensive study of a localized area would be of value in predicting site productivity differences.

Selection of Soil Tests-- Natural soil fertility of the arid, relatively unleached soils of the pinyon-juniper zone would appear to be too high to limit plant growth. Tarrant [1949] found in Douglas fir, which occupies sites in higher precipitation zones than pinyon, that moisture availability was the limiting growth factor, not soil fertility. For this reason, it was decided to concentrate on tests which might show that growth was limited by an excess or presence of a certain chemical condition. Gates, Stoddart and Cook [1956] have shown that the concentration of soluble salts, exchangeable sodium, and related soil conditions influence the distribution pattern of some desert vegetation.

An attempt was made to determine the degree and depth to which a profile had been leached by comparing the chemical content of the various horizons. This information was related to available rainfall data [Jenny, 1931]. Jenny and Leonard [1934] used the depth to lime carbonate concentration as an indicator of rainfall in loessial prairie soils from Colorado to Kansas. They also obtained good relationships correlating increasing rainfall with higher colloidal clay content of surface, lower soil pH, higher percent nitrogen, and higher cation exchange capacity. They stress the fact that uniform vegetation, preferably grassland, and uniform parent material are necessary for successful leaching estimates.

After considering the time and funds available, it was decided to run a preliminary study on the soil samples from 13 plots. Each horizon sample was analyzed for total soluble salts - (TSS), electrical conductivity of the saturation extract - (EC_e), total sodium - (TS), and total potassium - (K). All tests were made in the Utah State University Soil Testing Laboratory according to procedures outlined in the U.S.D.A. Agriculture Handbook No. 60, "Diagnosis and Improvement of Saline and Alkali Soils." The Wheatstone bridge was used to determine the approximate salt content of the soil as expressed by TSS and EC_e. The flame photometer and the prescribed extraction techniques were used to measure TS and K.

Preliminary Study-- The thirteen (1964) tree plots selected for the preliminary study represented four of the best tree sites, three of the poorest sites, and six medium sites. All these sites had soil profiles which were deeper than 25 inches, and fractured bedrock conditions did not appear to be a possible site factor. Five of the sites had sandstone parent material, two had coarse alluvium parent material, three had limestone parent material, and one site each had loess, shale, or acid igneous parent material. Soil pit elevations ranged from 5600 feet to 8100 feet, and sites were scattered over the entire study area.

TSS, EC_e, and TS values were obtained for each horizon, and the values were plotted against depth. Observed tree root conditions were taken into account by drawing perpendicular lines from the "depth axis" of each site graph (Figure 5.c.1).

Values of TSS ranged from less than 0.03 to 0.45 percent. EC_e values ranged from 0.435 to 10.038. TS values ranged from 0.15 me/liter to 3.30 me/liter. In all cases, the higher values are associated with higher salt or sodium concentrations.

Examination of the profile graphs led to the following conclusions.

i. The concentration of total soluble salts as measured by TSS (Resistance through a Bureau of Soils Cup), EC_e (Conductivity of the extract of a saturated soil), and TS (Total sodium, as determined by the flame photometer) showed the same curve form within each profile.

ii. High salt or sodium concentration within any horizon of the profile, including the major root zone appeared to have no relation to tree growth on a site. However, physical factors such as cementation which accompany high salt concentrations in some cases may be a limiting factor.

iii. The use of salt or sodium concentration to measure the depth of leaching or water movement has limited value because these salts have a

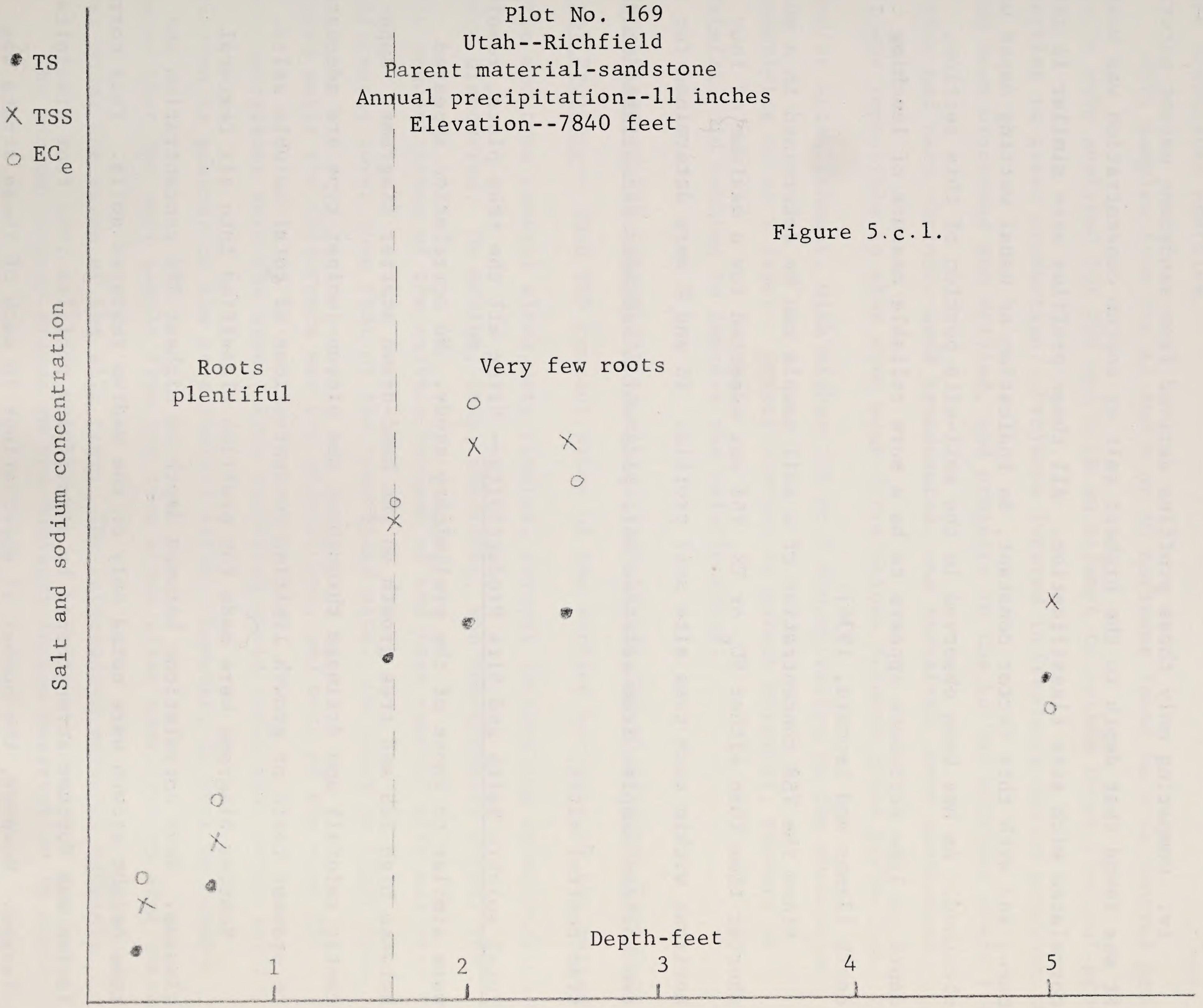

Figure 5.c.1.

Plot No. 169
Utah--Richfield
Parent material-sandstone
Annual precipitation--11 inches
Elevation--7840 feet
● TS
X TSS
○ EC$_e$
Salt and sodium concentration
Roots plentiful
Very few roots
Depth-feet
1
2
3
4
5

tendency to move rapidly through the profile in response to precipitation or evaporation. In several of the profiles, salt and sodium concentration was highest at the surface, or was evenly distributed throughout the profile, even when rainfall information, profile development, texture, and lime concentrations indicated that substantial leaching had taken place.

iv. Comparing only those profiles derived from sandstone parent material, it was found that depth to the highest salt or sodium concentration was weakly correlated with site classification. All these profiles were similar in texture, and with this factor constant, an indication of usual wetting depth was obtained. As has been observed in the soil-site portion of this section, depth to lime carbonate appears to be a more reliable measure of leaching depth [Jenny and Leonard, 1934].

Since the TSS concentration of a soil sample can be determined in a much shorter time than either EC_e or TS, TSS was measured for a maximum of four horizons within each tree site soil profile. TS and K were determined for the two horizon samples from selected soil pits which had been established on the tree control sites.

Total soluble Salts and Site Productivity-- Using all the tree plots, results were similar to those of the preliminary study. No correlation appeared between high TSS and tree growth on the hand-drawn scatter diagrams. Apparently rainfall and drainage throughout the pinyon-juniper type are adequate to prevent toxic or growth limiting concentrations of total soluble salts.

Scatter diagrams were made for profiles classified into six textural classes. Weak correlations between depth to highest TSS concentration and tree height growth were noted only on the medium textured soils. This correlation was further strengthened by stratifying profiles into four precipitation classes. However, the number of observations in each of these strata was probably not sufficient to give a statistically reliable estimate of the correlation.

The results from the heavy and light textured soils, as well as the very rocky or gravelly soils, showed no correlation between tree growth and depth of leaching as determined by depth to the highest TSS concentration in the associated profiles.

Soil samples from the A1 and B or AC horizons found on tree control projects were analyzed for TSS and K in an attempt to relate these chemical properties to grass production. Projects located in Escalante-Sevier province that had been windrowed and drilled, and projects in the La Sal province where the trees had been chained, seed broadcasted, and rechained, were considered. It was impossible to show even weak correlations between grass production and/or establishment, with either TSS or K concentration in the surface or underlying AC or B layer. Stratification by parent material, texture or rainfall did nothing to improve the relationships.

Comparison of TSS Concentration within Tree Stands and on Adjacent Tree Control Projects-- When TSS concentration of the surface horizons of the paired tree and tree control sites were studied, several interesting relationships were discovered. On medium, deep, non-rocky, and non-gravelly sites, the TSS concentration of the surface horizon of the tree control site was significantly lower than that of the tree stand site. On heavy or light textured soils the difference was not significant, and most of the time TSS concentrations were the same. This condition would imply that water infiltration is greater on the tree control sites. However, it must be remembered that the soil sample from the tree stand sites came from an area which was under the crown of the site tree. The interspaces were not sampled.

The pinyon-juniper stands on the Hualapai Indian Reservation in northwestern Arizona were burned in place, and then broadcast seeded. It was found on nearly all of these projects that the TSS concentration was higher on the burned areas than within the undisturbed tree stands. The grass stands on these projects were very productive and vigorous, relative to projects with similar climatic and soil conditions. Apparently the heat of the fire was not intense enough to destroy soil nutrients, but raised fertility by releasing minerals from existing litter and tree growth.

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6. WOODLAND TREE CHARACTERISTICS AND TREE CONTROL

Robert J. Rivers

The purpose of this section is to consider and evaluate the efficiency of tree control techniques from the standpoint of tree mortality and regrowth. Forage production relationships are discussed in another section of this study [Section 7].

The broad classes of pinyon-juniper control are combustible, mechanical, and chemical. Tree-killing chemicals had not been employed on any of the sites visited.

Mechanical techniques used on the study sites were cabling, single chaining, double chaining, and bull dozing. In chaining, two crawler tractors move through the trees with a long loop of cable or anchor chain stretched between them. Trees are caught in the loop and up-rooted. The weight of the chain is between 45-90 pounds per link, and the length is great enough to permit a 50-150 foot swath through the treatment area. Double chaining is the same as single chaining except that it is repeated twice in opposite directions. Cabling is the same as chaining except that a heavy mine cable (1"-1.75" diameter) is used in place of an anchor chain. Where per-acre tree stocking rates are low, bulldozers are used to rip out individual trees. (Costs per tree are quite high, but kill results are very good.)

Controlling pinyon-juniper lands by fire may be either accidental or intentional. Plots catalogued as "burned" included sites that initially may have been chained and later burned as well as several controlled burns and the site of one wild fire.

The earliest control techniques were either hand chopping or individual tree burning [Hull and Doran, 1950]. It was not until 1951 that chaining or cabling became a widely used control technique [Cotner, #210].

Information concerning pinyon-juniper control and tree kill is fragmented, influenced by local practices, and not readily obtained. Most published research relies upon data of recent origin and may be briefly summarized as follows. Cost studies made by Cotner and Jameson do point out the influence of tree size on control costs [1963]. Several studies also indicate that it is basically impossible to obtain a reasonable kill by chaining or cabling trees whose heights are less than 10 feet [Arnold et al., 1964]. Aro (formerly with U.S.G.S.), while evaluating control methods for the BLM, obtained significant correlation coefficients when comparing kill percentage vs. percent of trees greater than 20 feet and also for percent of trees greater than 10 feet on projects that were single chained. He was unable to obtain the same degree of statistical reliability when he pooled his data for both single and double chaining [Aro, 1965]. However, aside from statistical difficulties, his data indicate that possibly the 10 foot height class is the break-off point as far as satisfactory kill percentage is concerned.

Space occupied by pinyon-juniper and its relation to forage production is of prime concern to the range manager. It is now a generally accepted hypothesis that as crown canopy of the woodland species increases, understory forage production decreases [Arnold, et al., 1964; Arnold and Schroeder, #18]. A significant portion of the effort of the personnel performing the present study was devoted to a test of this hypothesis. The results are reported in Section 7.

The length of time for tree regrowth is also another unknown. It has been observed that residual trees missed by chaining or cabling do show a considerable increase in growth rate [Arnold, et al., 1964; Aro, 1965]. However, what this rate means over the long run is still unknown. The only "longevity" study has been reported by Cotner who estimates that tree stands with an average age of 13 years and 52 years are producing only 94 percent and 29 percent respectively of their potential forage production. He relied upon data supplied by Arnold, Jameson and Ried [1964], which in turn, came mainly from "invasion" situations. Whether the trees "released" following cabling would be the same size when 52 years old is unknown. Similarly, except for Cotner's suggestion that tree seedling establishment occurs at the rate of five trees per acre per year in northern Arizona, little is known about this additional important variable [Cotner, 1963].

In more northernly sections of the study area it seems that the effect of heavy slash on forage production should be considered if mechanical control is used. Aro has noted that, of the sites he visited, control debris covered an area that varied from 10 percent to 50 percent, with the average being 25 percent [1965]. The adverse effects of excessive slash have also been mentioned by Arnold _et al_. [1964]. (Slash remaining after bulldozing ordinarily is not a problem; similarly, if slash is winrowed, a much smaller land area is affected.)

Basic Data-- The data used in this section were collected from one hundred and sixteen (one tenth acre) plots located on pinyon-juniper control projects throughout the five state area. Thirteen plots were deleted from the statistical analysis; nine which had been subject to more than one treatment and four which exhibited terain difficulties non-typical for the site area.[1]

Field Measurements-- The following data were collected from each 10 'x 43.6' plot: (a) diameter outside bark at 1 foot by species for all living and dead trees; (b) number of trees under one foot (1') by species for living and dead trees; (c) trees were recorded as live (standing) or live (on ground); (d) estimate of slash cover;[2] (e) whenever possible three (3) tree disks were also collected on each site.[1]

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[1] So much fuel wood had been/cut from some of the cablings (mainly BIA areas) that kill and slash percentages were difficult to estimate.

[2] This estimate was obtained by converting each pile of debris into the area of a rectangle. For single trees the slash cover was considered 75 percent of the rectangular area covered by the crown. For large piles of slash, the area covered was considered 100 percent of the rectangular area.

6.a. Percentage Kill-Tree Diameter Correlation

Investigation of the relationships between a measured tree characteristic and percentage kill took several forms. It was found that kill percentages associated with various control techniques bear little relation to basal areas, average diameters per acre, or total number of trees per acre. The most promising approach requires that percent kill be related to percent of tree stand $\geq$ 7 inches in diameter at 1 foot. This approach is not affected by differences between ecological provinces.

The plot data were then analyzed statistically in the following model for a linear regression:

$$\log Y = \log b_0 + b_1 \log X \quad ,$$

where

Y = percentage kill

X = percentage of stand $\geq$ 7 inches diameter at 1 foot.

Each control method was analyzed separately: chaining one way (54 plots); chaining two ways (22 plots); burning (18 plots); and cabling (9 plots).[2]

Analysis and Discussion-- The results of machine analysis of the tree kill data are:

1. Chaining one way:
   $\log Y = \log 6.18 + 0.6113 (\log X)$
   $R^2 = 0.898$

2. Chaining two ways:
   $\log Y = \log 16.5 + 0.4035 (\log X)$
   $R^2 = 0.924$

3. Burned:
   Formula is not shown as R^2; was only 0.276

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[1] The collection area was not limited to the fixed plot. The criterion for selecting a disk was that it come from a live, standing tree, relatively free of stem damage.

[2] Cabling observations were two few for statistical analysis.

Figure 6.a.1
Kill and one way chaining

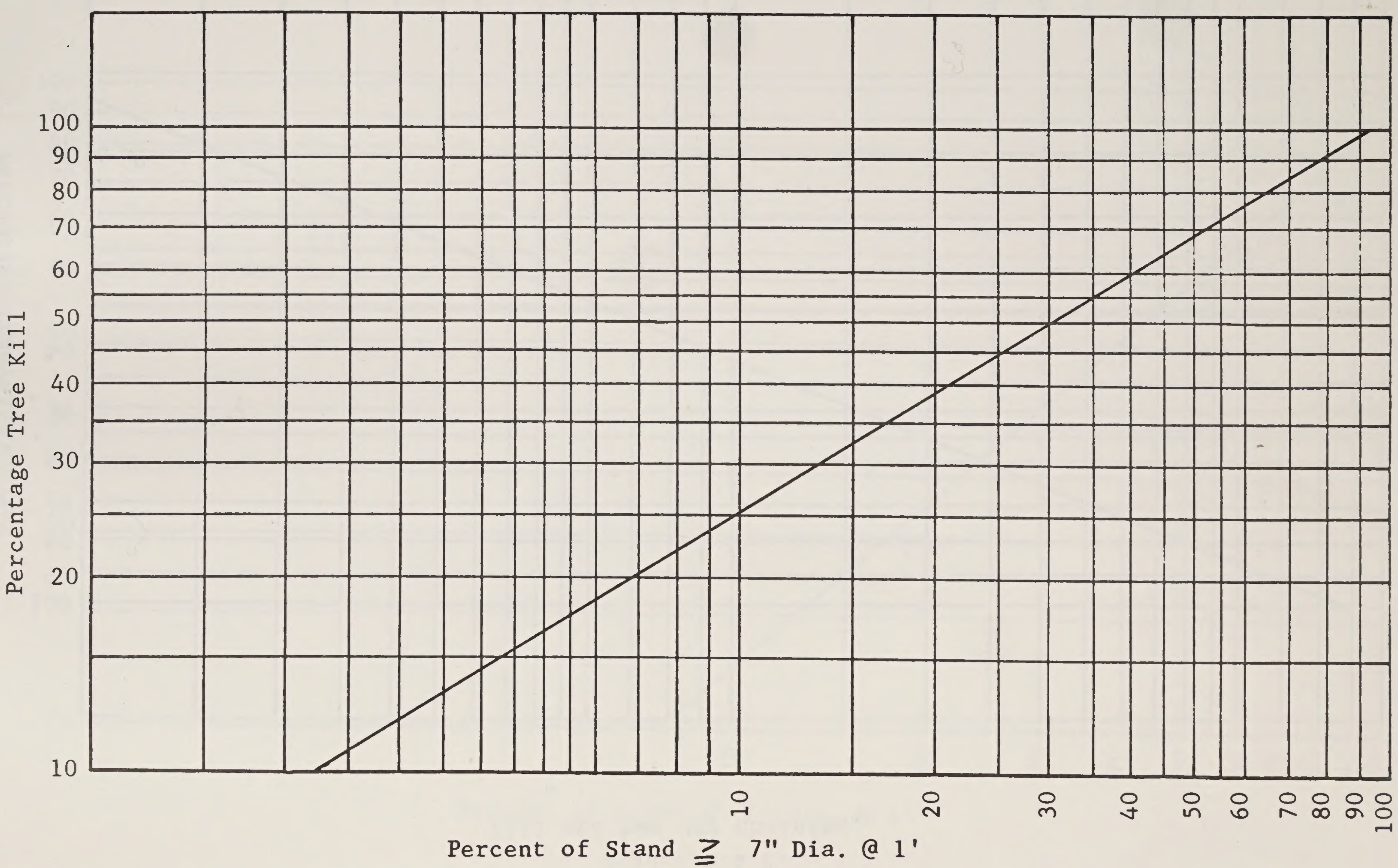


Figure 6.a.2.
Kill and two way chaining

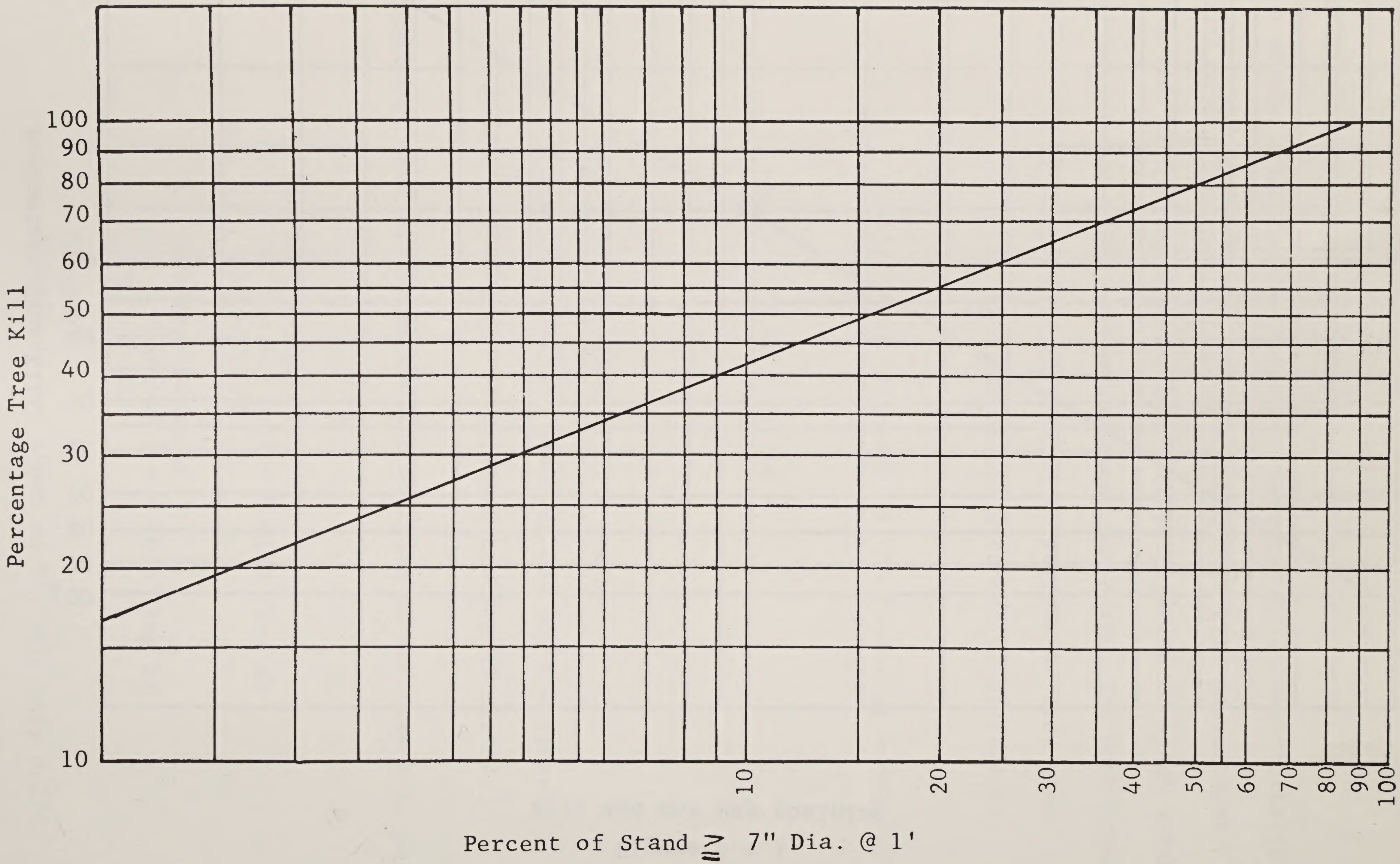
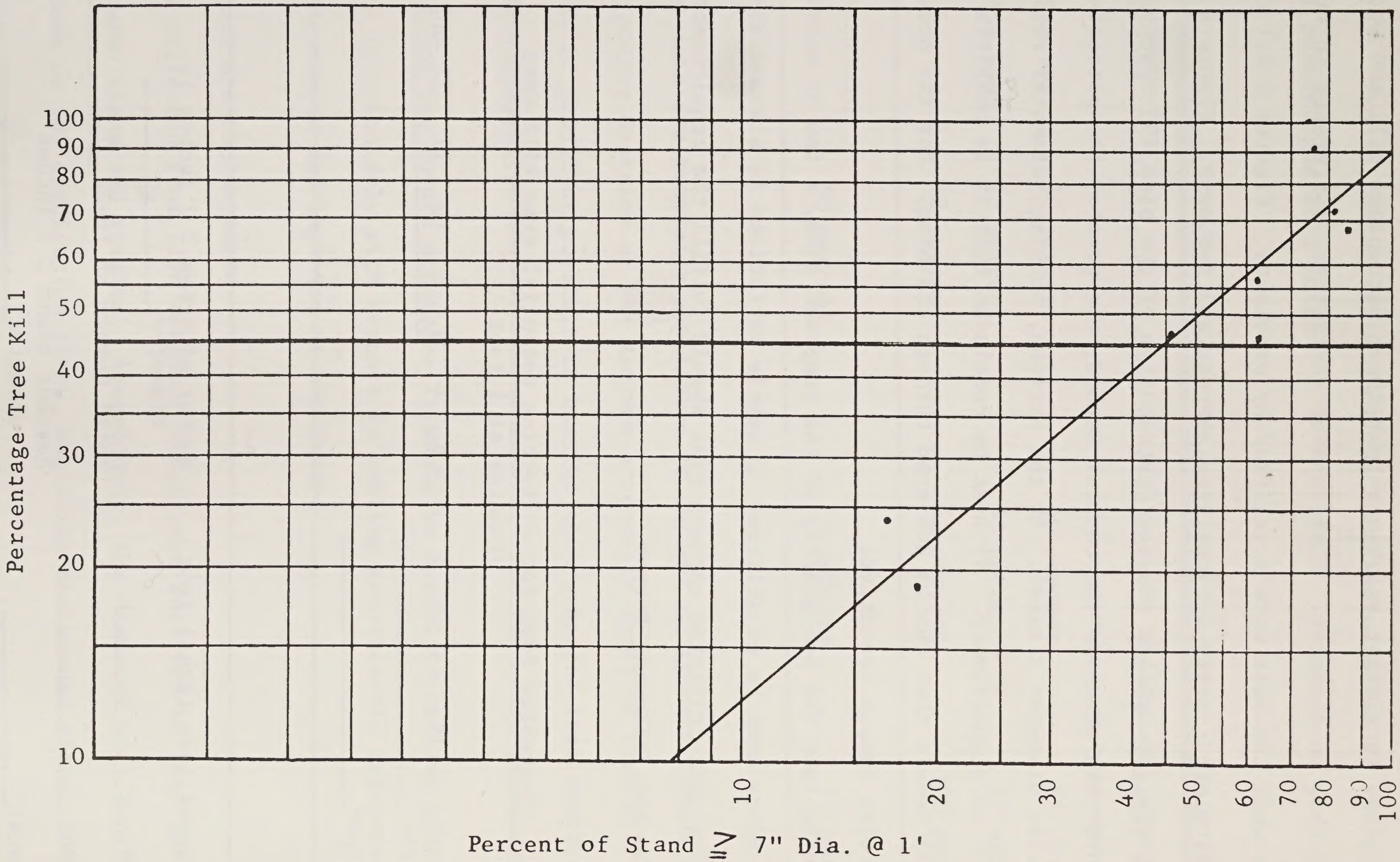


Figure 6.a.3.
Kill and cabling



The results for sites which were burned indicated, as might be expected, that there is no consistent relationship between percentage kill and percent of stand ≥ 7 inches in diameter. There was no statistical difference in tree kill percentages when the data were stratified by provinces. Figures 6.a.1 and 6.a.2 show the calculated curves for chaining one way and two ways. Figure 6.a.3. is a suggested curve for cabling showing distribution of the nine (9) observations.

The more comprehensive the control method, the greater the percent kill of the smaller diameter classes. At the extreme, burning, diameter relationships are of no significance. It must be concluded that it is possible to predict kill levels that can be achieved through chaining. For the present, cabling results remain tentative.

Depending upon the homogeneity of the proposed site, a few or several one-tenth acre plots must be established to sample variations in stand diameter classes. The data collected on each plot should fulfill the requirements indicated by the following format.

Table 6.a.1. Suggested form for collecting potential tree kill data

	Diameter at 1 foot										
	1	2	3	4	5	6	7	8	9	10	11	12 and etc.
Number pinyon ______												
Number juniper______												
Sub-totals												

Number of trees less than 1 foot

Pinyon______

Juniper______

Sub-total______

Number of trees ≥ 7 inches in diameter ______

Total number of trees______

Percent stand ≥ 7 inches diameter______

The percent tree kill that any land manager is willing to accept should be one of the prime criteria by which a stand is judged worthy of expenditures for tree control. The following table provides some appreciation of the range over which kill percentages will move.

Table 6.a.2. Percent of stand above 7" necessary to achieve a given kill level

Control method	Necessary percent of stand over 7 inches diameter @ 1 foot		
Chaining one way	30 percent	60 percent	85 percent
Chaining two ways	15 percent	45 percent	78 percent
Cabling	52 percent	85 percent	100 percent
Acceptable percent tree kill	50 percent	75 percent	95 percent

These data are generally applicable to current management trends and, once the broad policy decision of the minimum acceptable level of tree kill has been determined, it should be possible to examine each proposed tree control site in the manner suggested.

Recommendation for future studies-- It would be useful to collect additional observations (particularly with respect to cabling experience); regression equations could be developed and improved as necessary.

6.b. Direct Growth Responses

Data collected from live residual trees were analyzed to test the relationships between sizes and species. Accordingly, the diameter at 1 foot of all living trees on 103 eradication plots, excluding the burned sites, were analyzed to determine means and variances.

In addition to the above, disks were collected from 173 trees on 60 of the above mentioned plots in an attempt to determine if any relationship existed between tree diameters and growth increments following conversion. Unfortunately, it was too time consuming to collect an adequate number of "control" discs in woodland stands adjacent to each plot. Only some generalized conclusions can be drawn.

Analysis and Discussion-- It is unlikely that pinyon pine under 3 inches in diameter will be knocked down by chaining or cabling. Trees in the 3-5 inch diameter class will be knocked down, but they may not die.

Junipers smaller than 3 inches in diameter will probably remain erect. Those in the 6-9 inch diameter classes will be knocked down but not necessarily killed. These are some of the conclusions suggested by the data in Table 6.b.1.

The major difference between species was in terms of trees left alive on the ground. Pinyon appeared to be more susceptible to mortality after having been pushed over. This trait may be due to differences in root systems, and relative inability to recover from stem injuries inflicted by the conversion apparatus. Juniper trees appear to be quite tenacious and unless the root system is severely (not just partially) injured, they may be expected to survive (even those in the 6-9 inch diameter classes). A live tree on the ground probably affects the site just as much as a live standing tree does.

Table 6.b.1. Diameter characteristics--residual trees (85 plots)

	Standing trees					Downed trees				
Species	Total	No. Live	% Live	Mean diameter	Variance	Total	No. Live	% Live	Mean Diameter	Variance
Pinyon	170	156	92	1.9"	+1.17	77	18	24	3.1	+2.34
Juniper	229	208	91	2.3"	+1.24	329	105	32	5.9	+2.98

This summary of residual tree data demonstrates the importance of selecting the 7-inch diameter class as the criterion upon which to base estimates of tree kill.

Table 6.b.2 summarizes the results of an attempt to relate tree "release" and subsequent growth rates to actual conversion dates. Data from 60 conversion sites were stratified in such a manner as to show the number of maximum growing seasons since the time of conversion. The diameter classes are the estimated diameter class (D.O.B.) of individual trees at the time of conversion. On each disc the number of rings exhibiting a marked increase in growth rates was determined by a student who had no knowledge of conversion site histories.

Despite what often appear to be obvious evidences of "release" in the growth rings of many discs, the present analysis indicates that there is no significant difference in percent response between species or even between the diameter classes.[1] The most significant result is that the major portion of instances of apparent response took place at the beginning of the fifth growing season following control. Only 27 percent of the sample showed response attributed to the control technique before the fifth year following control. After the fifth post-eradication growing season, the incidence of apparent response was 79 percent. Choice of any year following the fifth produced nearly the same result.

Figure 6.b.1 is a picture of a disc taken from a Juniperus osteosperma on the Navajo Indian Reservation in Arizona. The site was converted in 1957; the disc was collected in September 1965, or 9 growing seasons later. Obviously, not all discs exhibited as much apparent "release."

Recommendations for future studies-- Set up permanent study plots on the older conversion sites and determine how long growth response will last.

6.c. Conversion Site "Longevity"

Since few definite conclusions about direct growth response of residual can

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[1] Nevertheless, it is believed that additional observations, coupled with "control" discs, would produce positive results.

Table 6.b.2. Growth response of residual trees--following tree control

	1" diameter class				2" diameter class				3" diameter class				Summary all diameter, all species	
	Pinyon		Juniper		Pinyon		Juniper		Pinyon		Juniper			
Number of post-eradication growing season	No. of trees	% apparently exhibiting release	No. of trees	% apparently exhibiting release	No. of trees	% apparently exhibiting release	No. of trees	% apparently exhibiting release	No. of trees	% apparently exhibiting release	No. of trees	% apparently exhibiting release	No. of trees	% apparently exhibiting release
2	7	14	11	18	1	0	4	0	1	0			24	12
3	12	33	12	42	4	50	3	33			1	0	32	38
4	7	43	9	33	4	25	6	0					26	37
5	4	100	4	100	1	100	1	0	2	50			12	83
6	10	80	13	54	1	100	1	100			1	100	26	37
7	4	75	6	67	2	100	2	100					14	79
8	6	83	8	87	1	100							15	87
9	10	90	8	63	2	100					1	100	21	81
10	--	--	1	100	1	100	1	100					3	100
Total	60	61	72	53	17	65	18	28	3	33	3	67	173	54

Note: 1. % exhibiting apparent release from 2nd-4th growing season following control is 27%

2. % exhibiting apparent release from 5th-10th growing season following control is 79%

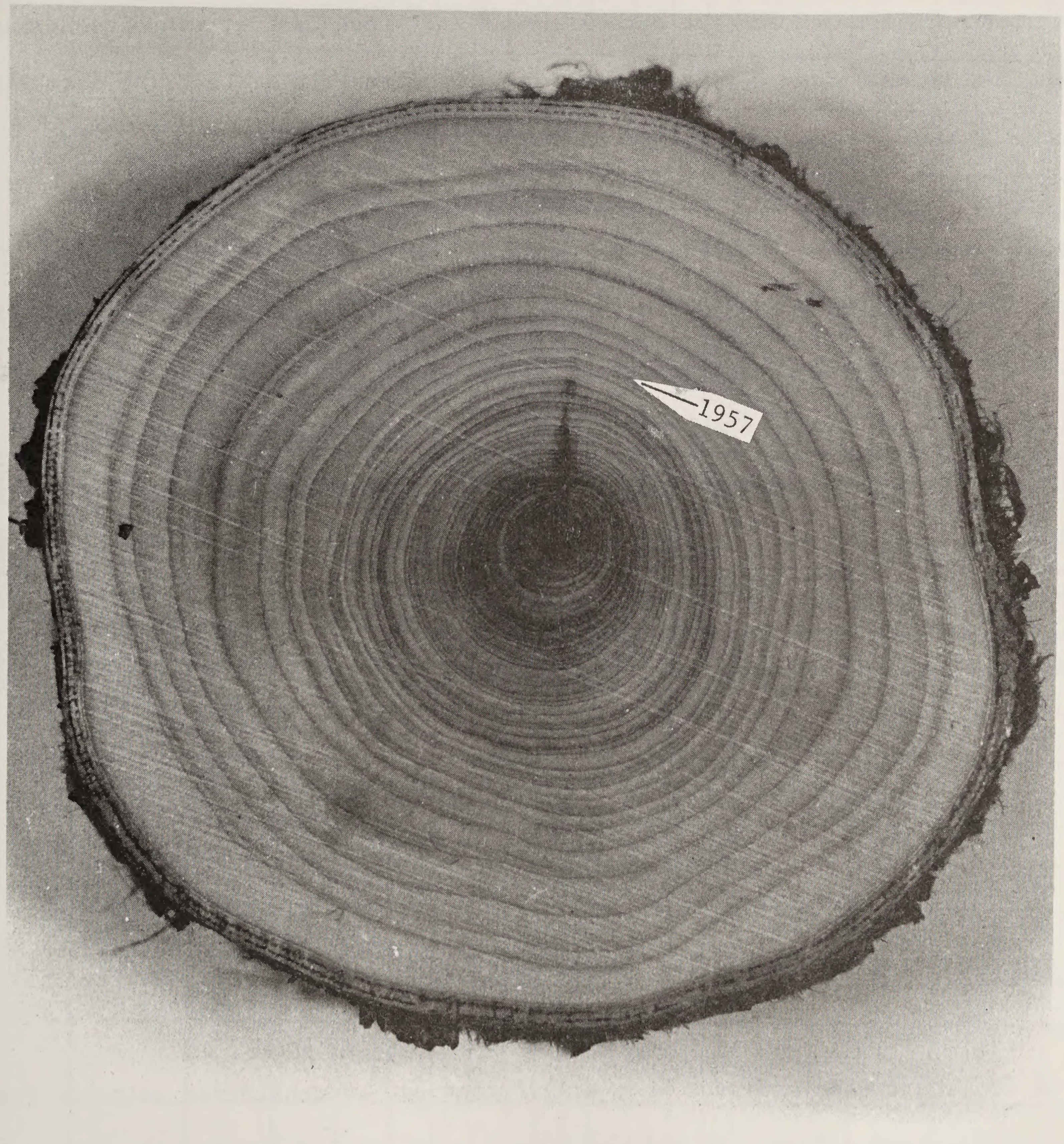

Figure 6.b.1.
Apparent "release" in a Juniperus
Osteosperma disc

be drawn at present, some indirect means must be found whereby "life" of a conversion having residual trees can be estimated. In this sub-section a scheme to predict the length of time necessary to develop 10%, 30%, and 50% crown closure (given an initial stock of residual trees) is presented. It must be born in mind, however, that the computations make no allowance for the establishment and subsequent growth of seedlings.[1] (The system may be modified to allow for any hypothesized rate of seedling establishment.)

The computations are based on the curves shown in Figures 6.c.1 and 6.c.2. These curves were developed from the tree height-crown diameter curves explained in section 4.c and from a series of height-age curves developed specifically for this portion of the report. The data supporting these latter curves are the same as those used in the age curves found in section 4.b. In the present instance the age data have first been summarized in order to arrive at the average age for a given height class and stratified into 5 height or site-class combinations. The data were fitted to the following general function

$$\log Y = \log a + b (\log X),$$

where

Y = height

X = age @ 1'.

Analysis and Discussion-- The results of the height-age analysis are summarized in Tables 6.c.1 and 6.c.2.

All of the regression analyses were significant and are considered suitable for height-age predictions. Curves 10.a.1 and 10.a.2 were developed primarily for application in woodland inventory techniques and will be discussed in a later section of this report.

Tree heights for curves 6.c.1 and 6.c.2 were extended to the theoretical limits

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[1] Only sketchy data appear to be available on this point.

Figure 6.c.1.
Pinyon
Height-Age Curves
All Provinces

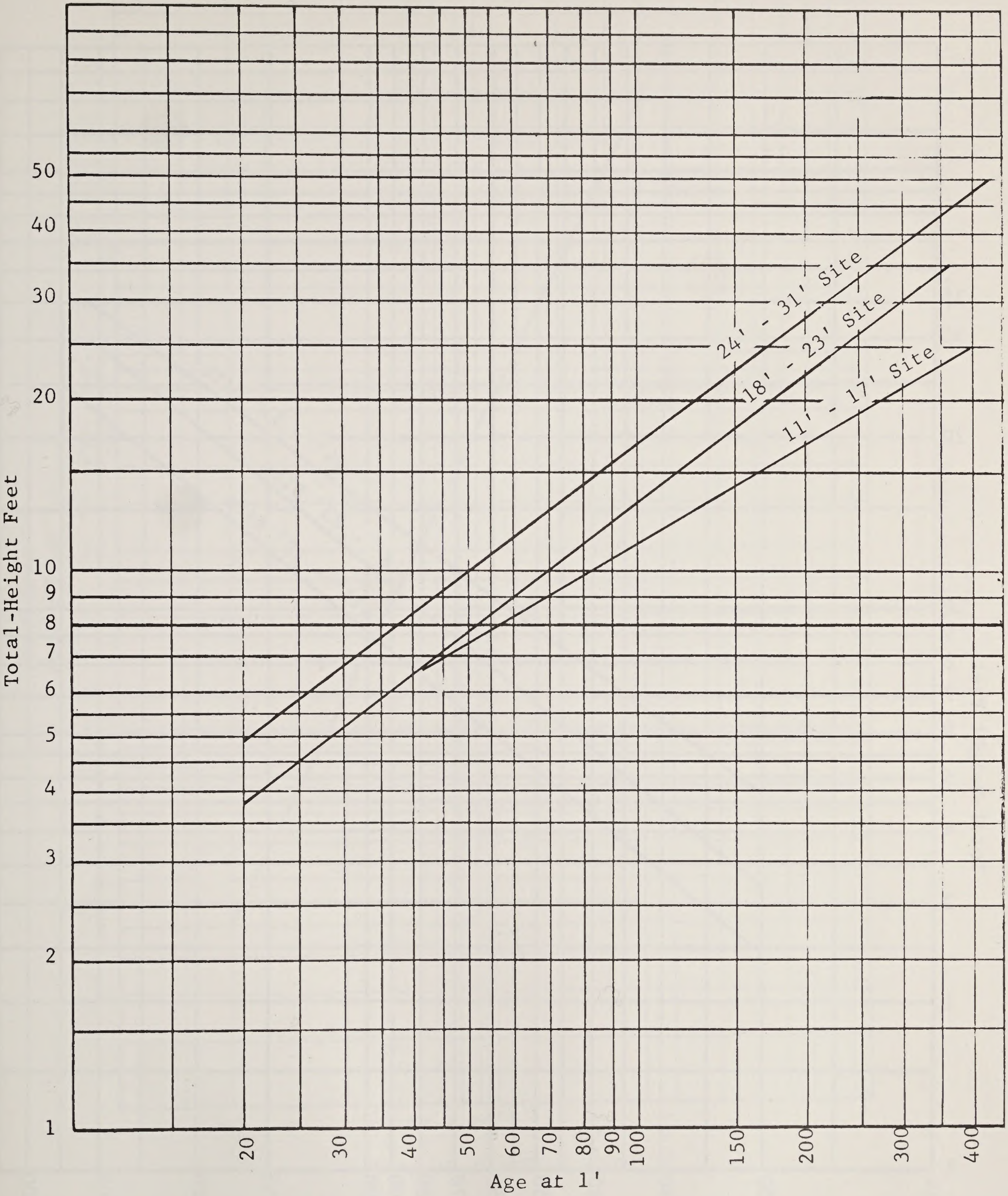
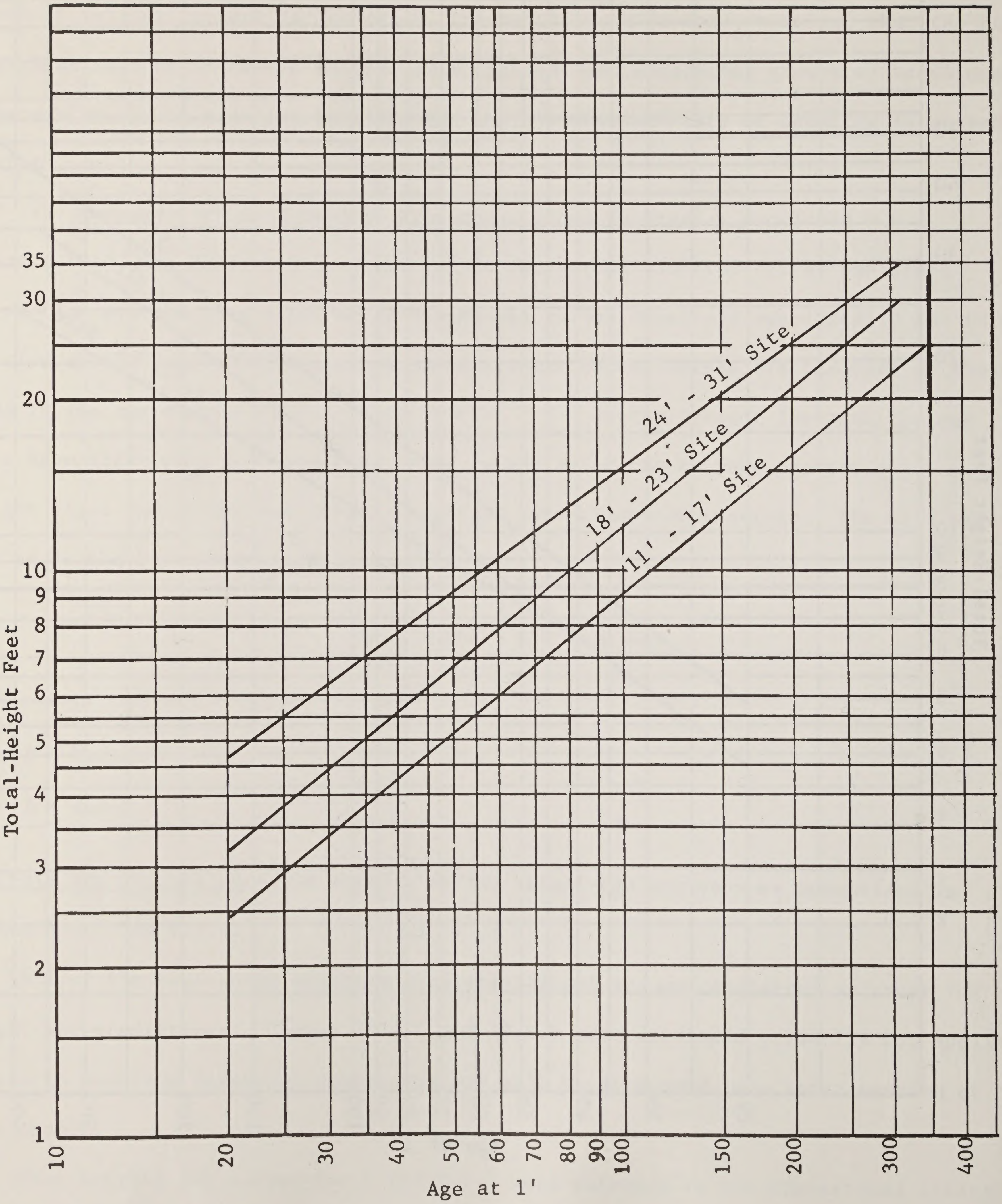
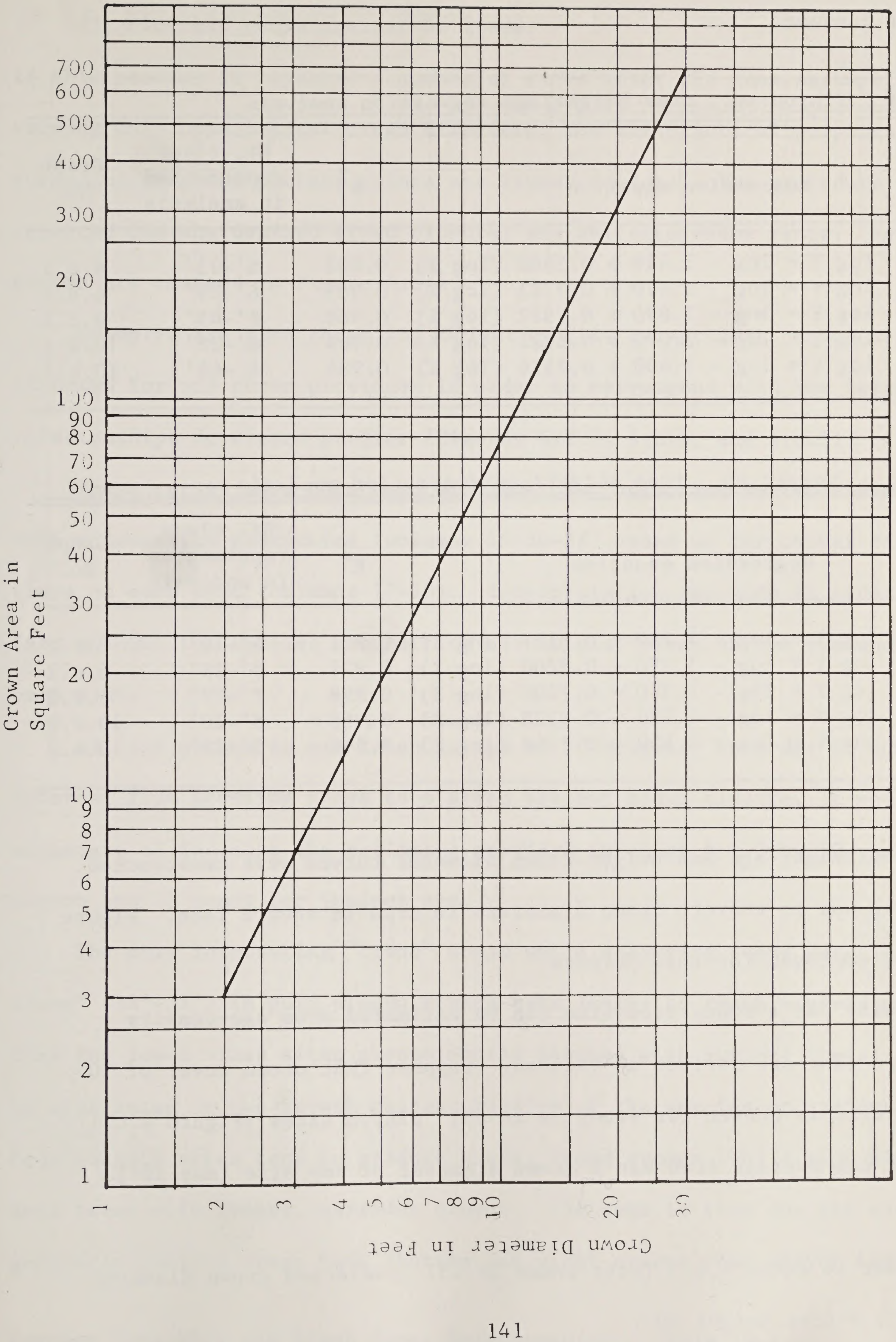


Figure 6.c.2.
Juniper
Height-Age Curves
All Provinces





Crown Area-Crown Diameter Conversion Chart
Figure 6.c.3.

of each site. For pinyon they were extended to 25'-35' and 50' and to 25'-30' and 35' for juniper.

Table 6.c.1. Pinyon sp., tree height/age regression analysis

Site class	Regression equation	R^2	Ht. class represented in analysis	Graph No.
11'-17'	$\log Y = \log - 1.410 + 0.5968 (\log X)$	0.947	6'-23'	6.c.1
18'-23'	$\log Y = \log - 2.670 + 0.7711 (\log X)$	0.965	6'-29'	6.c.1
24'-31'	$\log Y = \log - 1.890 + 0.7522 (\log X)$	0.968	8'-45'	6.c.1
11'-20'	$\log Y = \log - 2.070 + 0.6921 (\log X)$	0.966	6'-28'	10.a.1
21'-31'	$\log Y = \log - 3.400 + 0.8516 (\log X)$	0.984	6'-45'	10.a.1

Table 6.c.2. Juniper sp., tree height/age regression analysis

Site class	Regression equation	R^2	Ht. class represented in analysis	Graph No.
11'-17'	$\log Y = \log - 4.740 + 0.8137 (\log X)$	0.951	5'-19'	6.c.2
18'-23'	$\log Y = \log - 3.750 + 0.8200 (\log X)$	0.971	5'-25'	6.c.2
24'-31'	$\log Y = \log - 1.920 + 0.7309 (\log X)$	0.898	7'-27'	6.c.2
11'-20'	$\log Y = \log - 4.280 + 0.8128 (\log X)$	0.962	5'-20'	10.a.2
21'-31'	$\log Y = \log - 4.550 + 0.8768 (\log X)$	0.940	5'-28'	10.a.2

Once the height-age and height-crown diameter curves were constructed, the next step was to convert crown diameters to area in square feet. Figure 6.c.3 may be employed for this purpose.

"Longevity" of a conversion site can be estimated from age-density relationships that are derived as follows. Suppose that crown cover of 10 percent per acre is chosen for study on 24'-31' pinyon sites [Figure 4.c.1]. Imagine that the average tree has a crown diameter of any size (say 10'). Then:

(1) Refer to curve 4.c.1 (site index 24'-31', selected crown diameter 10') = tree height 20';

(2) Referring to curve 6.c.3, crown area for a 10' diameter = 77 sq. ft.

(3) Since 10% cover = 4.356 sq. ft., 4356/77 = 56 trees;

(4) From Figure 6.c.1, age for a 20' pinyon on site 24'-31' = 126 years;

(5) Plot 126 years against 56 trees.

If this process is repeated a number of times under the same assumptions, varying only hypothetical crown diameters, for all practical purposes, it turns out that the plotted points are linear in logs. The procedure may be repeated for any desired crown closure, and any site index range. Results for pinyon are charted in Figure 6.c.4.

Examples are also shown for juniper species except that curves were constructed for all three provinces in order to correspond with the height-crown relationships developed earlier (Figures 4.c.3, 4.c.4, and 4.c.5).

These curves were then used with the plot summaries in Table 6.c.3 to provide a longevity prediction (columns 19-20-21) based on the number of residual trees on each plot (columns 17-18). Interpretation was made in order to take into account the species composition and initial sizes of the residual trees on each plot.

All age estimates are taken as age at 1' height. In order to compute an interval from seedling stage to a given percent crown closure, it would be necessary to increase the estimates provided in chart 6.c.3 by 10 years for pinyon and 15 years for juniper spp.

The most interesting "trend" noted while analyzing these data is that "good sites" (24'-31') in pure pinyon stands take longer to reach a given percent canopy than the lower class sites predominantly stocked with juniper trees. This may be attributed to the growth characteristics of the species on various sites. Poor quality sites tend to produce short, broad crowns, while good sites produce trees with longer, narrower crowns. The same is true for the species; generally juniper trees have shorter and wider crowns than pinyon trees.

Percent Tree Kill and Slash Cover Relationships-- Table (6.c.4)

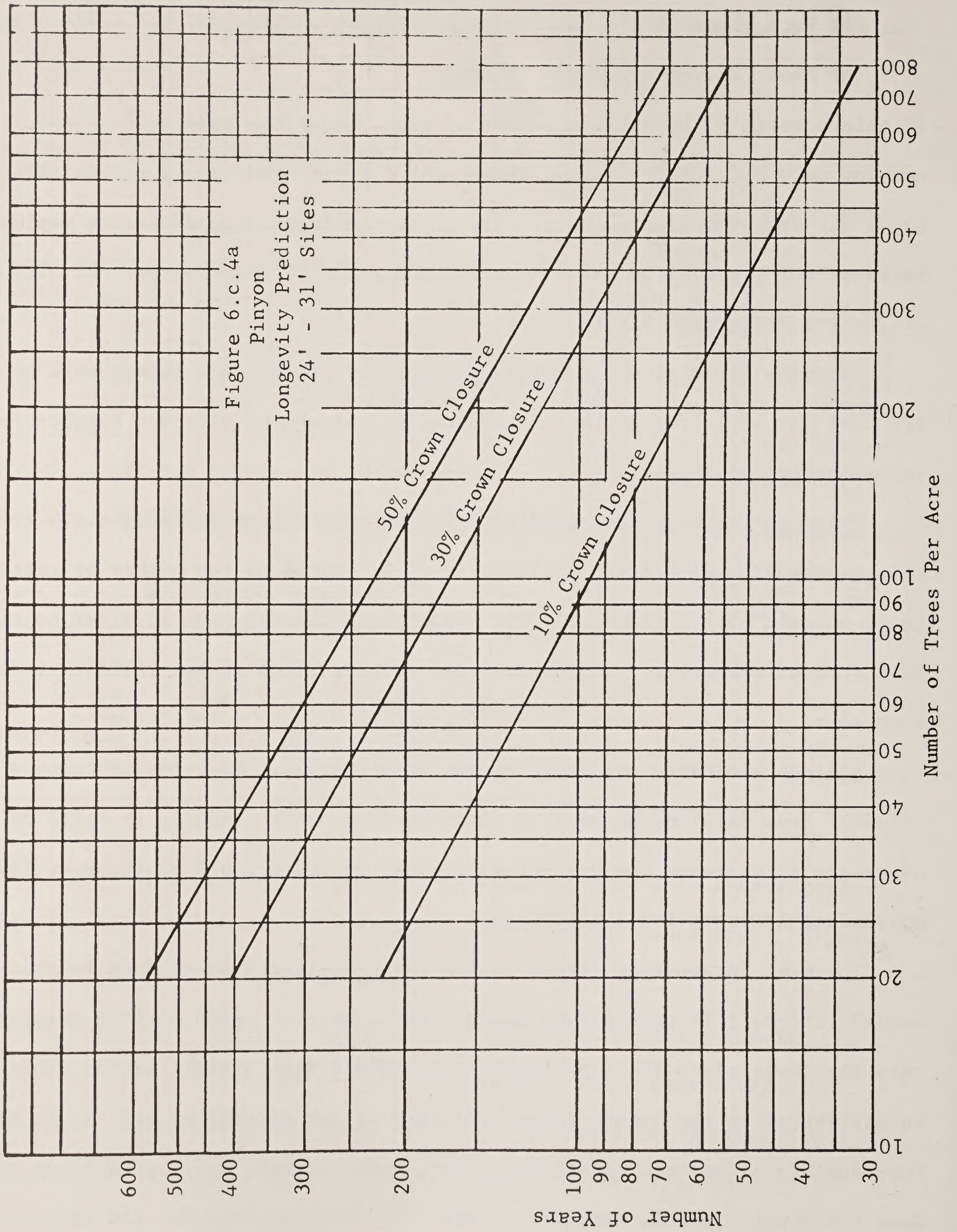


Figure 6.c.4a
Pinyon
Longevity Prediction
24' - 31' Sites

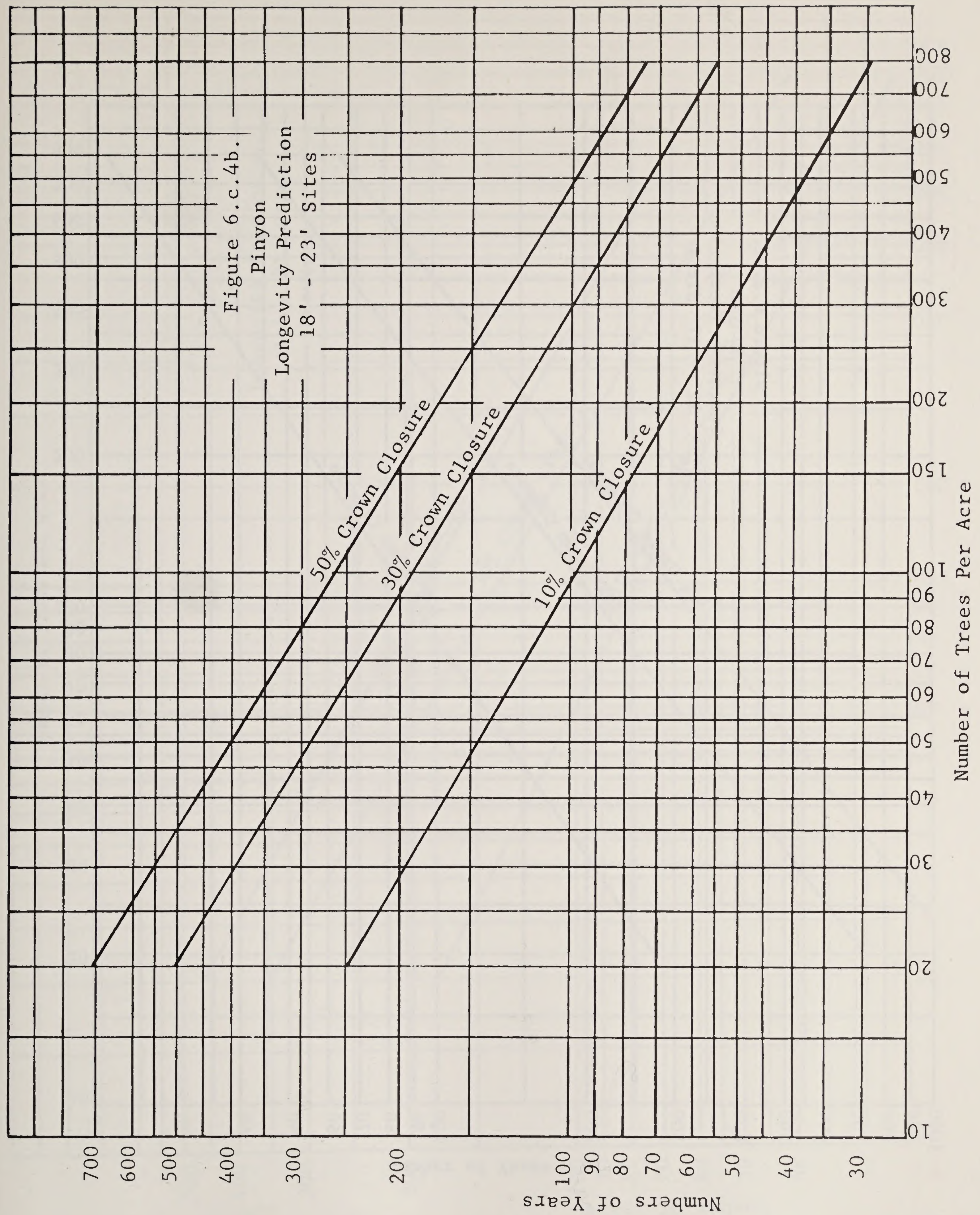


Figure 6.c.4b.
Pinyon
Longevity Prediction
18' - 23' Sites

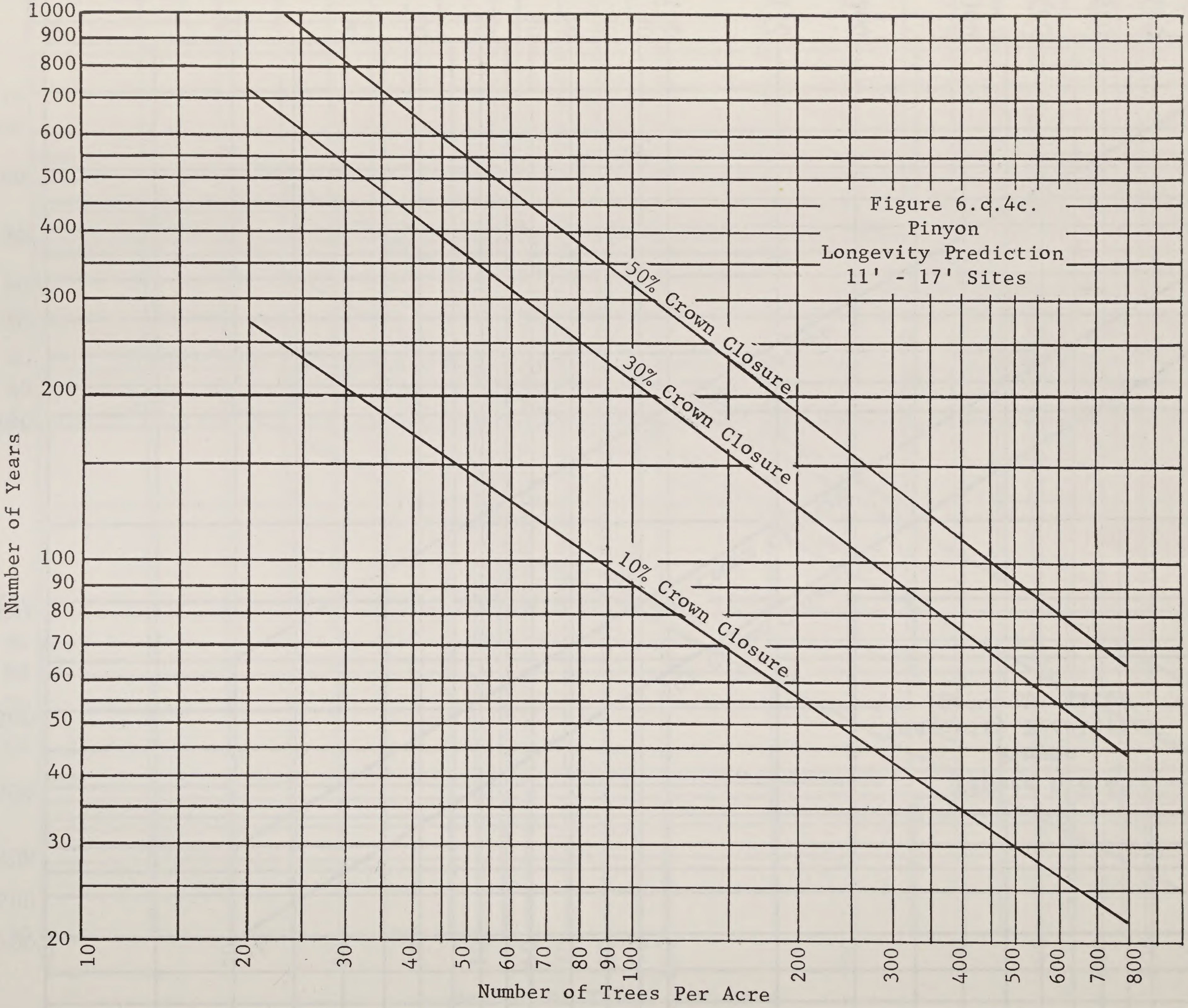
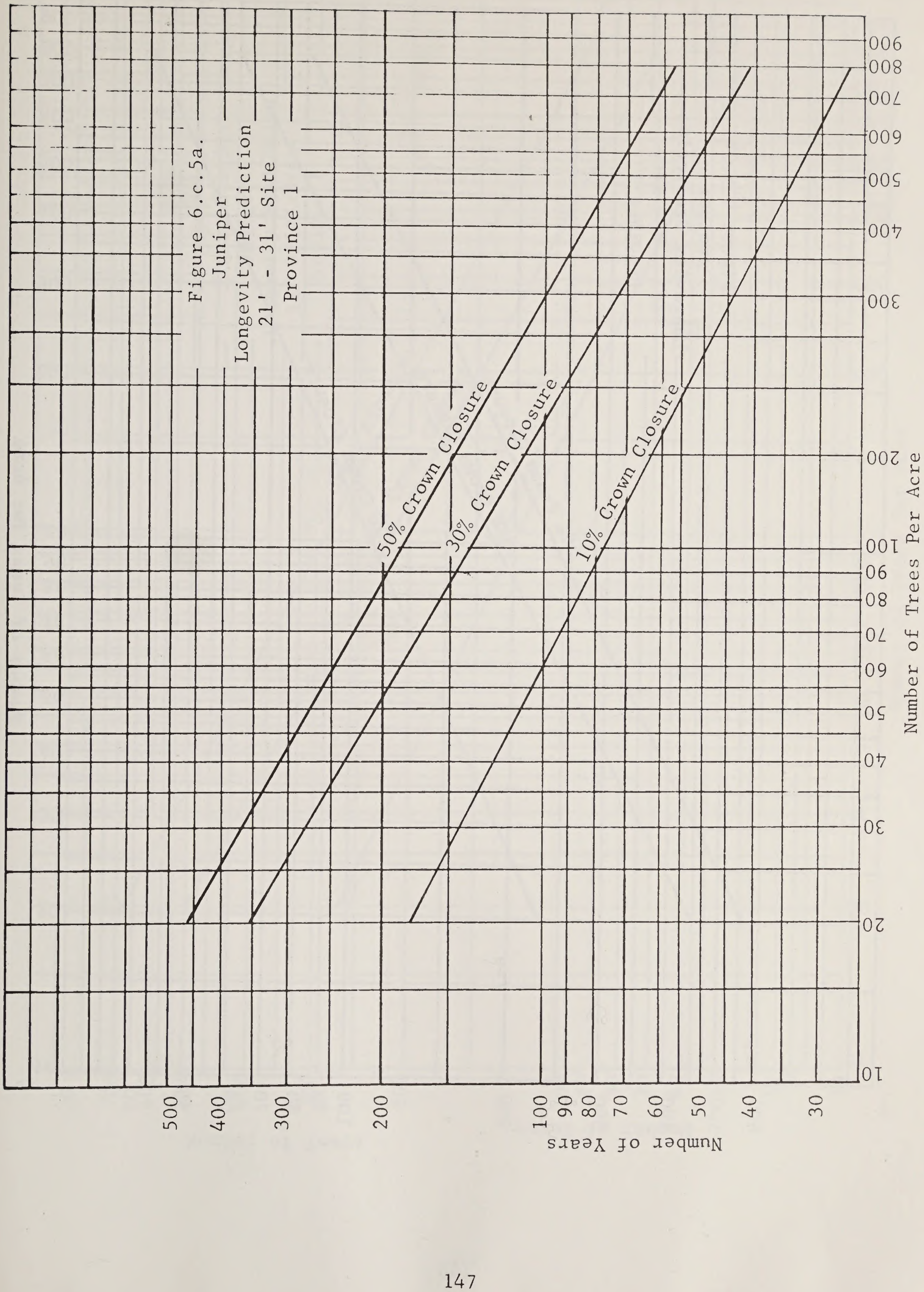


Figure 6.c.4c.
Pinyon
Longevity Prediction
11' - 17' Sites



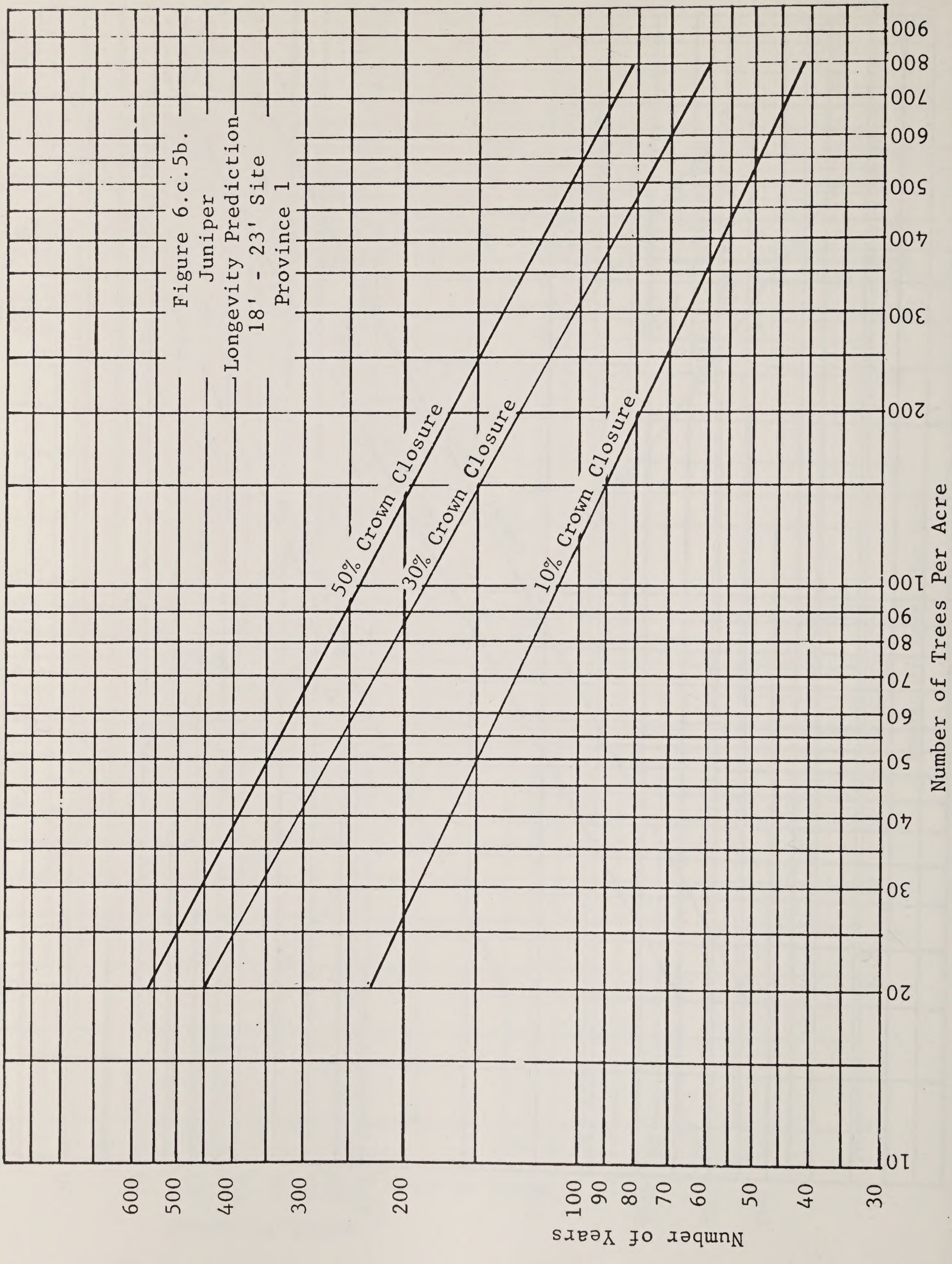


Figure 6.c.5b.
Juniper
Longevity Prediction
18' - 23' Site
Province 1

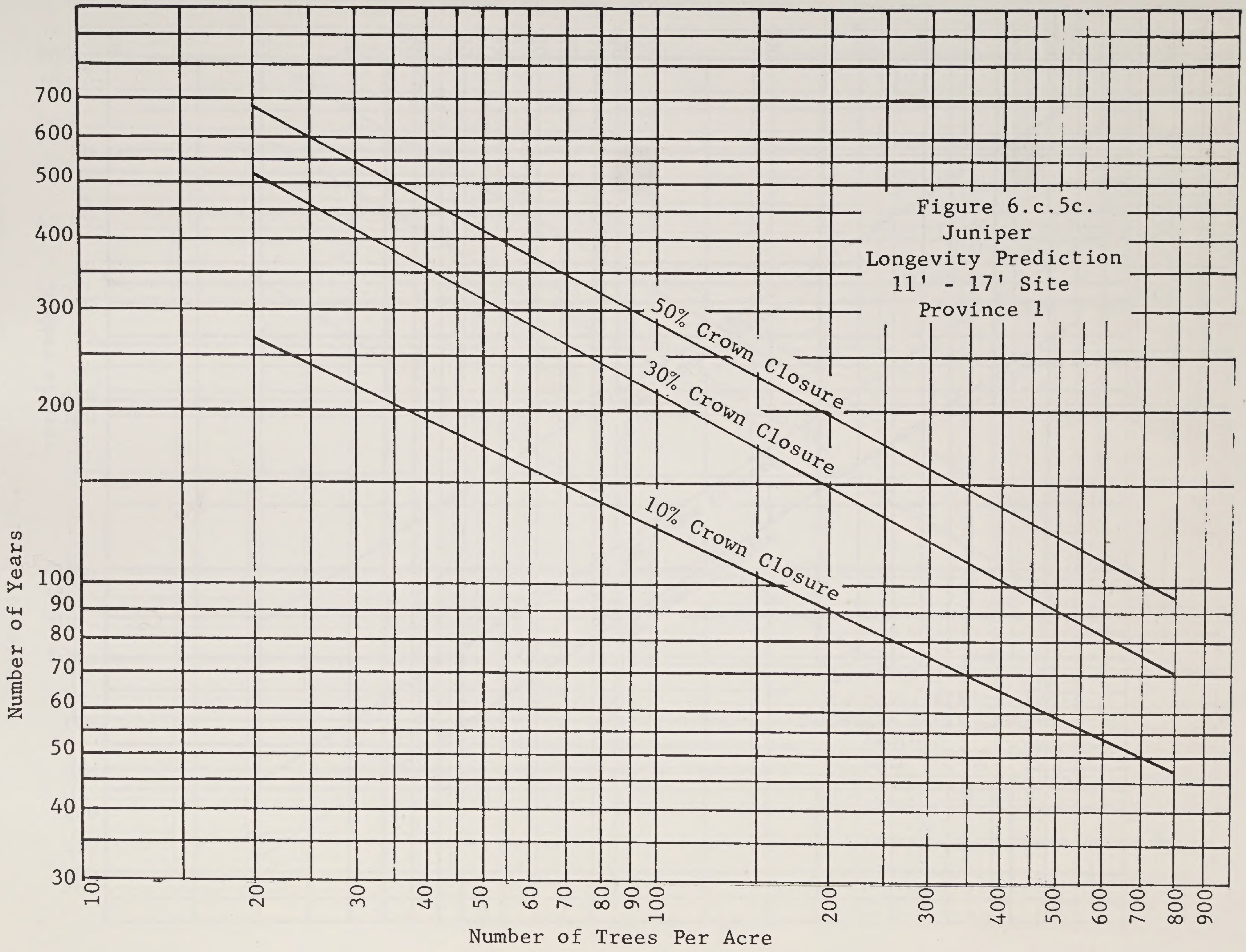


Figure 6.c.5c.
Juniper
Longevity Prediction
11' - 17' Site
Province 1

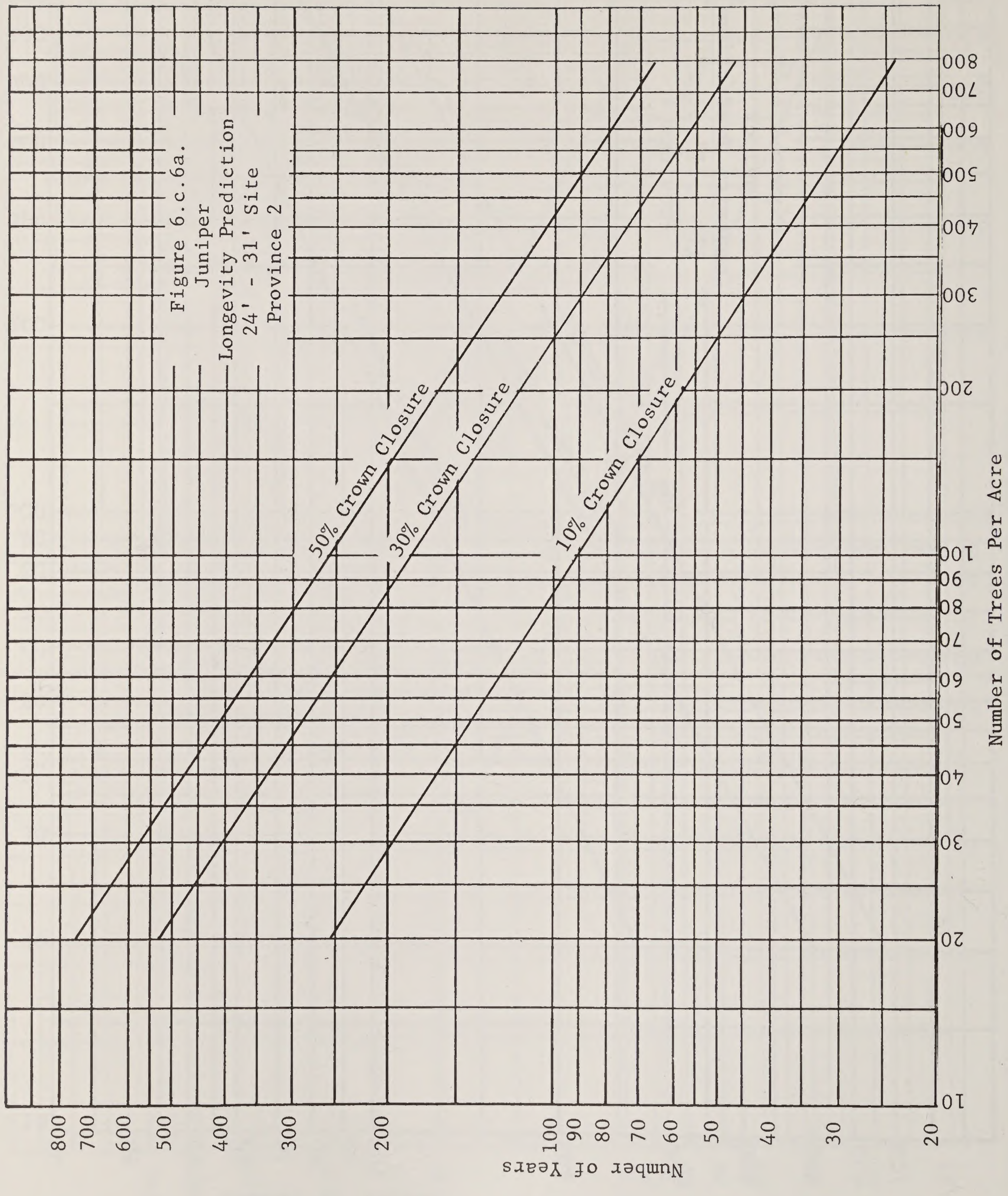


Figure 6.c.6a.
Juniper
Longevity Prediction
24' - 31' Site
Province 2

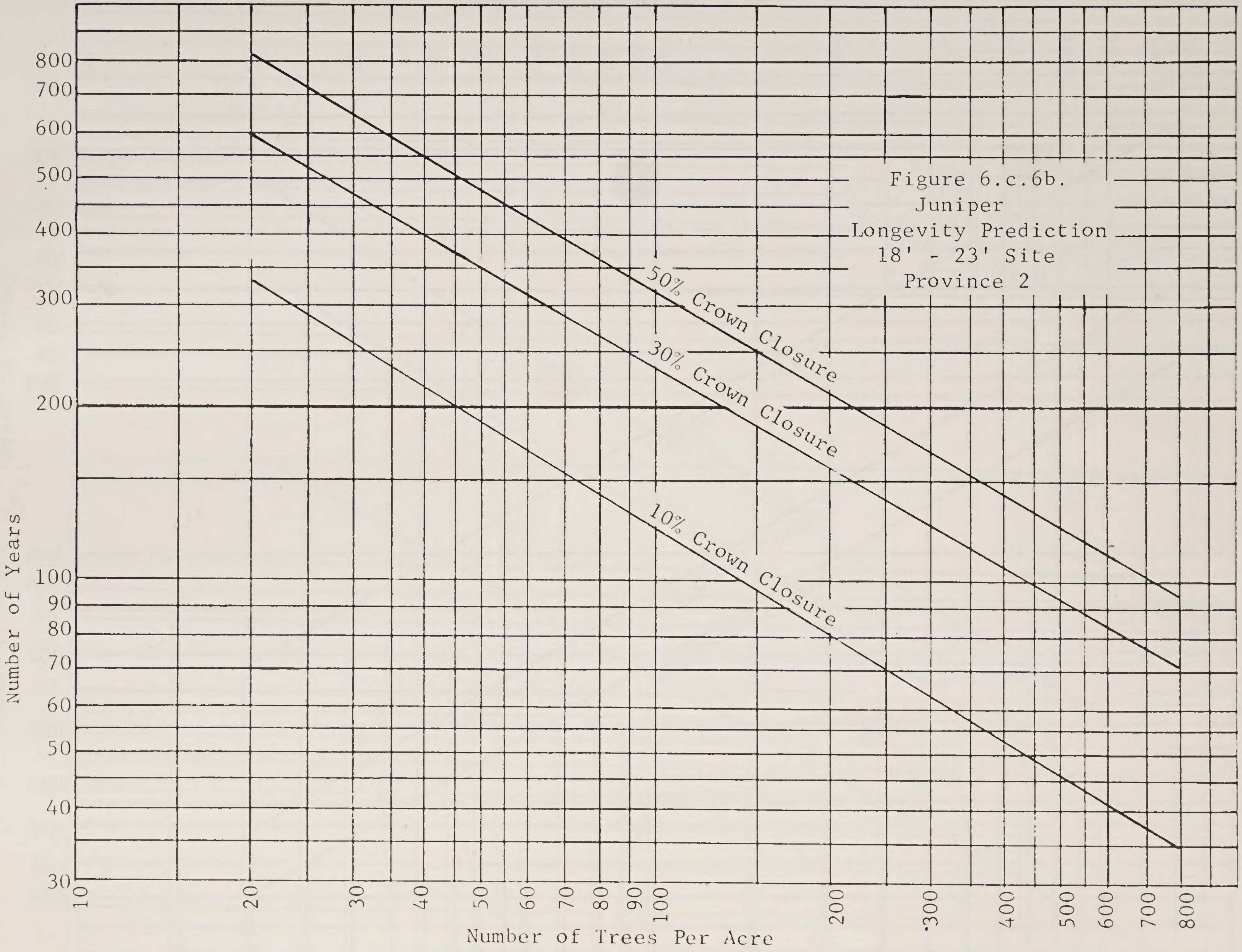


Figure 6.c.6b.
Juniper
Longevity Prediction
18' - 23' Site
Province 2

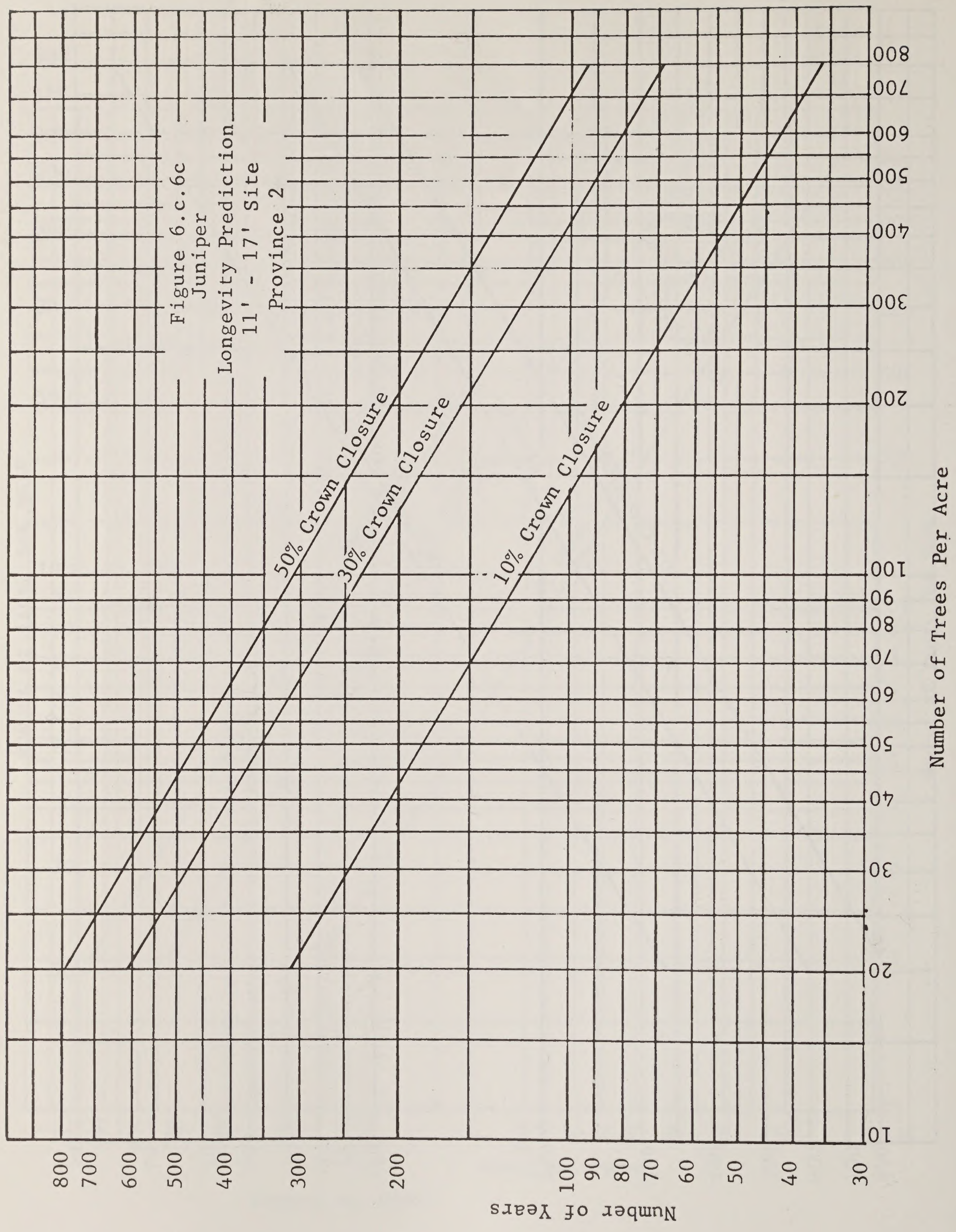


Figure 6.c.6c
Juniper
Longevity Prediction
11' - 17' Site
Province 2

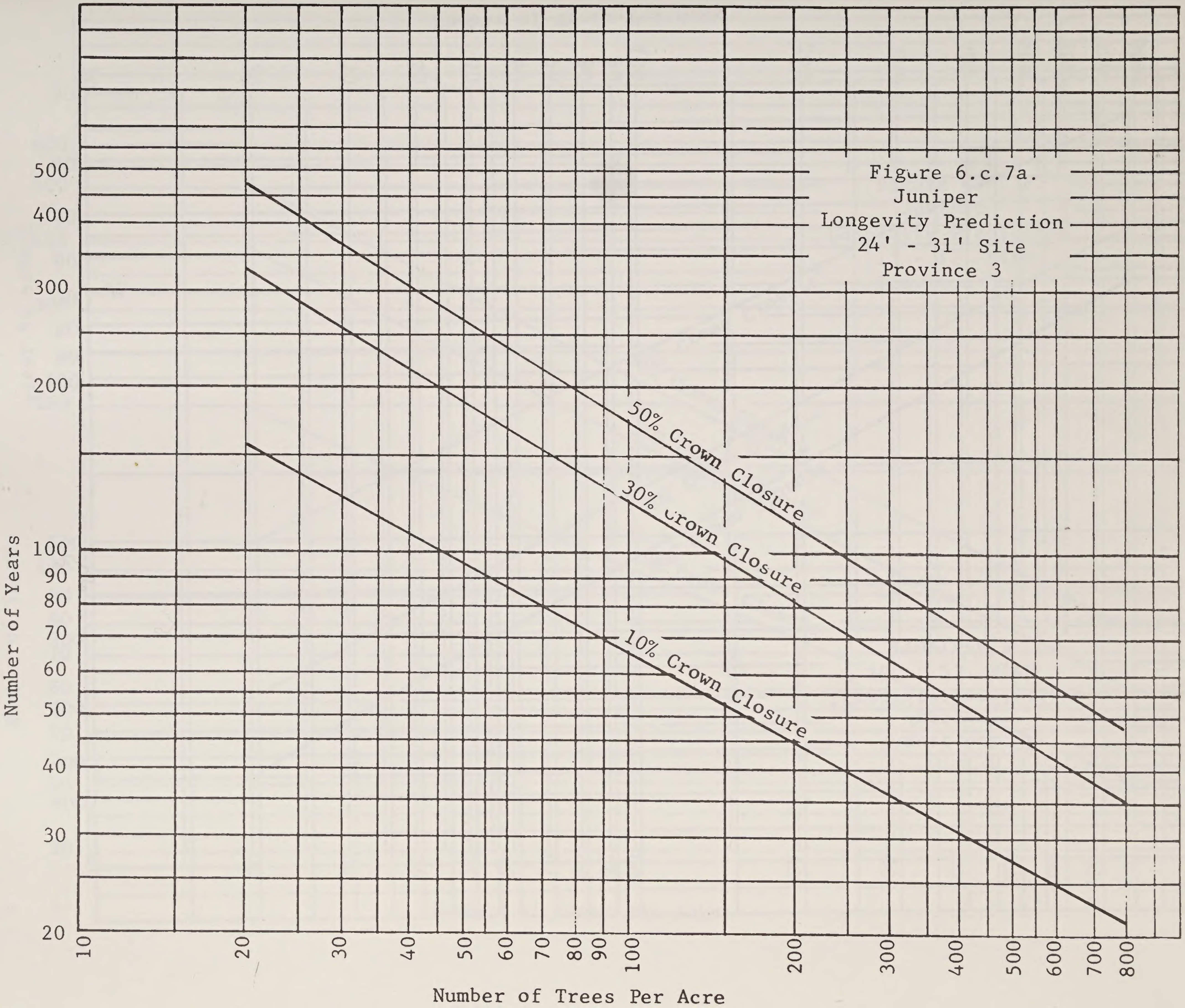


Figure 6.c.7a.
Juniper
Longevity Prediction
24' - 31' Site
Province 3

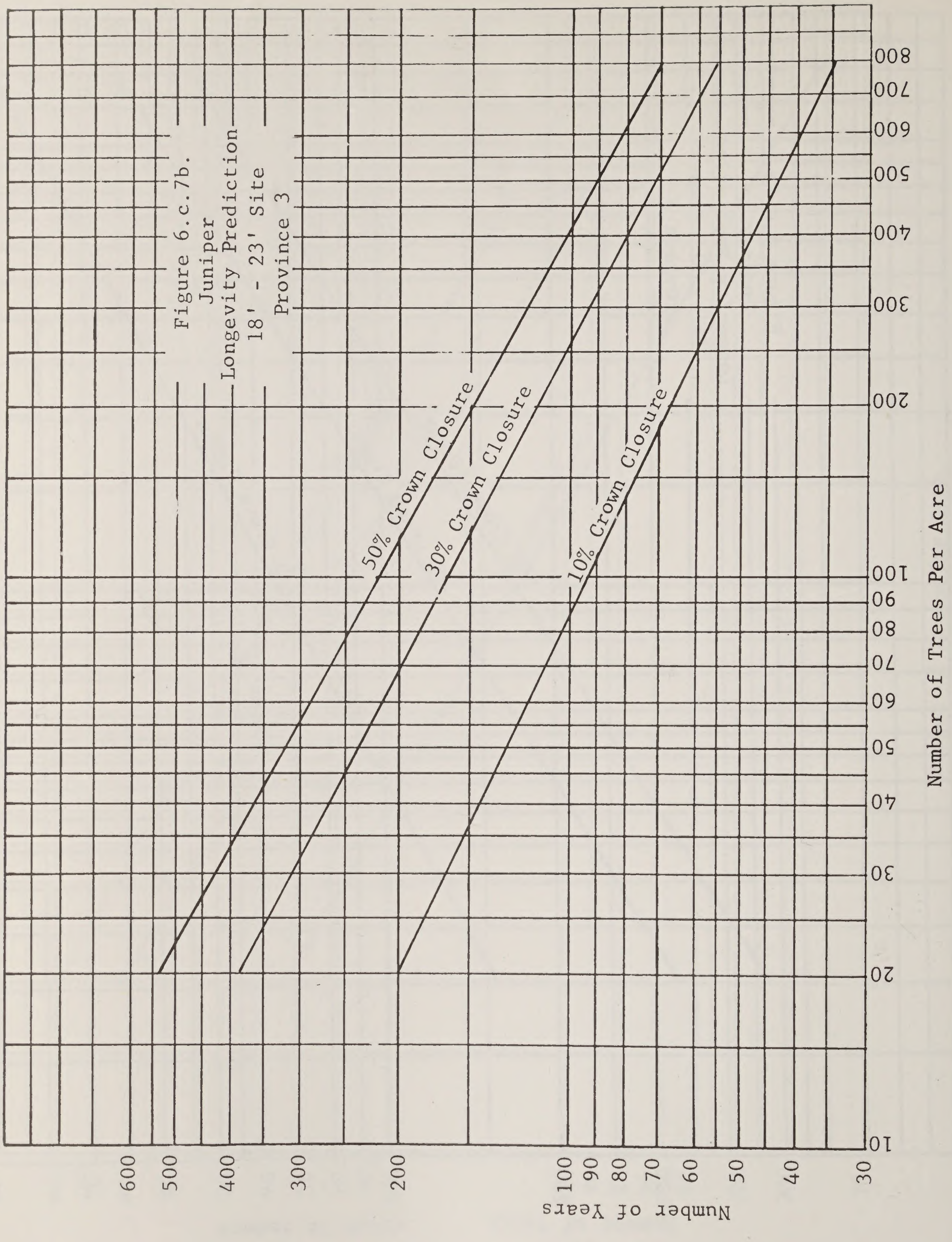


Figure 6.c.7b.
Juniper
Longevity Prediction
18' - 23' Site
Province 3

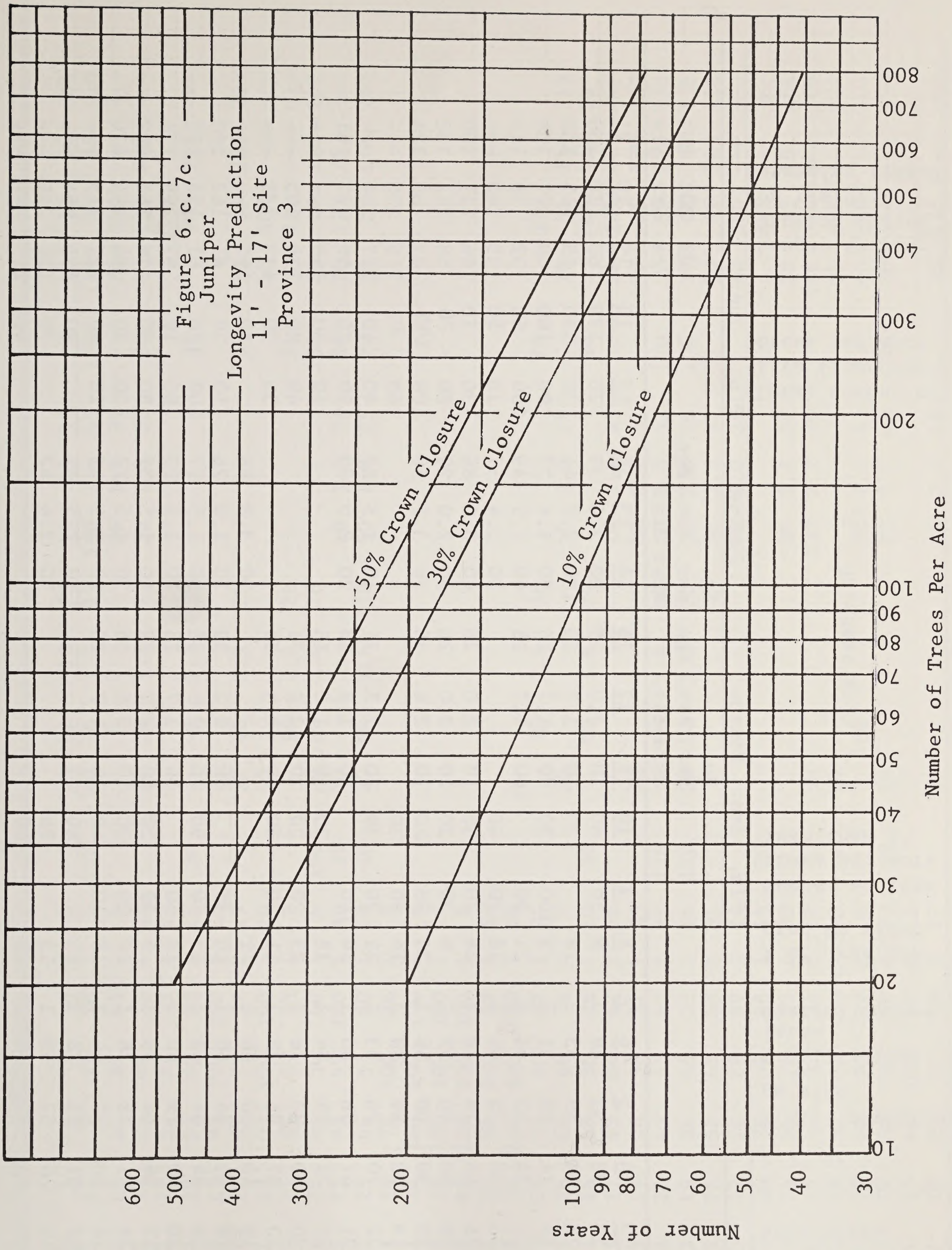


Figure 6.c.7c.
Juniper
Longevity Prediction
11' - 17' Site
Province 3

Table 6.c.3. Eradication plot summaries

			% Tree kill																	
Plot No.	Province	Site class	% of stand ≧ 7" at 1'	% kill measured on site	% kill calculated	Control method	% of area covered by slash	Number of live trees per acre less than 1'		Live standing > 1'						Total number of live (standing) trees per acre		Longevity prediction (based on residual standing trees)		
								Pin.	Jun.	Pinyon			Juniper			Pin.	Jun.			
										No. per acre	Ave. dia.	Age	No. per acre	Ave. dia.	Age			10% yrs.	30% yrs.	50% yrs.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
271	1	23	28	52	49	1	8	10	80	10	2.0	29	90	2.0	39	20	170	60	110	153
277	1	22	34	59	53	1	18		30	30	1.7	25	100	2.2	41	30	130	55	115	150
278	1	19	14	28	31	1	9	100	90	90	1.7	25	90	1.4	27	190	180	40	77	108
280	1	21	24	40	43	1	21	90		160	1.7	25	60	2.9	49	250	60	32	76	110
281	1	23	50	75	68	1	16	10	40				10	3.4	57	10	50	135	240	---
386	1	26	64	70	78	1	14	20	30	10	2.0	26	40	6.0	86	30	70	46	111	160
387	1	28	40	60	59	1	8	70	20	10	2.0	26	50	2.0	29	80	70	58	112	152
388	1	22	50	60	68	1	34	90	120	10	2.6	36	70	3.2	58	100	190	47	89	124
299	2	19	78	89	89	1	16	60	30							60	30	115	220	---
304	2	22	70	76	83	1	32	20	30	20	2.2	31	10	1.5	27	40	40	117	234	---
305	2	21	41	56	60	1	14	140		50	1.9	28	20	2.0	39	190	20	56	117	161
306	2	27	72	89	84	1	18		30	10	1.0	15				10	30	159	---	---
307	2	20	60	83	76	1	23	20	20	20	2.2	31				40	20	136	203	---
309	2	20	57	95	72	1	11	20	30	10	2.5	36				30	30	133	279	---
310	2	19	40	60	60	1	11						30	3.8	68		30	192	---	---
313	2	16	41	56	60	1	10	30		80	2.2	29	10	1.0	26	110	10	61	163	253
314	2	19	44	64	63	1	13	60	90	40	2.5	36	30	1.5	27	100	120	61	126	172
315	2	20	40	75	60	1	13	50		30	1.7	25	10	1.5	27	80	10	97	199	271
316	2	17	36	64	55	1	7	30	20	50	2.2	29	10	1.5	37	80	30	76	185	282
317	2	28	61	78	78	1	10	20	20	10	2.0	26	30	1.5	22	30	50	94	194	270
318	2	18	50	77	64	1	18	10	40	10	1.7	25	20	2.5	45	20	60	122	215	---
319	2	18	61	71	78	1	15		60				30	2.5	45		90	135	264	---
320	2	19	36	57	55	1	13		20				50	2.6	47		70	121	256	---
321	2	18	63	82	78	1	11		40								40	215	---	---

Table 6.c.3 continued.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
328	2	22	7	21	20	1	5	120	40	50	1.2	17	130	2.4	45	170	170	34	85	120
333	2	18	25	38	43	1	5						20	1.7	31		20	319	--	---
335	2	23	63	69	78	1	20		10	20	1.0	12	30	1.8	33	20	40	137	270	---
311	2	21	57	71	73	1	13													
336	2	22	57	65	73	1	17	30		40	2.3	33				70		103	221	---
337	2	27	92	100	100	1	15													
338	2	27	62	71	77	1	17		30	40	1.9	26				40	30	99	203	294
340	2	19	100	100	100	1	20		10								10	500	---	---
343	2	21	57	71	73	1	7			10	2.0	29				10		471	---	---
348	2	26	41	50	60	1	6	100	20	60	2.0	26				100	20	60	112	157
391-B	2	25	95	95	100	1	28	30	10				10	3.7	51	30	20	127	253	---
391-C	2	25	66	63	80	1	28	40	20	50	1.6	20	50	1.8	25	90	70	57	118	168
284	3	21	71	100	84	1	5													
286	3	24	100	100	100	1	8													
287	3	19	100	100	100	1	2													
288	3	19	100	100	100	1	8													
365	3	31	88	100	98	1	17													
366	3	23	100	100	100	1	18													
372	3	21	75	88	88	1	24			10	2.5	36				10		370		
381	3	26	60	66	76	1	9		20				50	2.0	29		70	59	134	219
383	3	26	18	36	36	1	10	20		60	1.8	24				80		87	117	237
398	3	17	43	64	62	1	24						10	2.2	45		10	225	---	---
399	3	17	38	56	57	1	23		70				60	2.5	51		130	66	129	130
N-2	3	24	43	65	62	1	25	110	10	60	1.8	24	20	2.3	32	170	30	52	100	138
N-7	3	19	34	46	53	1	16	110	20	90	1.3	18	30	2.6	46	200	50	46	98	136
N-8	3	25	52	68	68	1	31						50	3.3	47		50	49	143	218
S-14	3	17	78	89	89	1	24						10	1.0	26		10	270	---	---
A-18	3	26	88	100	98	1	13	10								10		305	---	---
Z-19	3	24	56	72	73	1	30						80	2.7	39		80	35	101	161
256	1	14	6	32	34	2	10		50				100	2.1	46		150	74	144	200
257	1	26	57	86	87	2	8		20								20	235	---	---
258	1	17	40	70	72	2	5			30			30	1.9	43		60	149	---	---
275	1	19	50	80	80	2	7	20	10				20	2.7	48	20	30	194	---	---
276	1	17	66	100	90	2	3													
377	1	18	85	92	98	2	17		20				10	2.5	46		30	175	---	---
293	2	16	61	89	87	2	17			20	2.0	34				20		236	---	---
296	2	19	58	74	85	2	10	30	20	30	2.1	33				60	20	108	220	---
302	2	25	69	100	91	2	17													

Table 6.c.3 continued.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
323	2	21	25	55	60	2	30	90	90	140	2.5	36	40	2.7	54	230	130	32	79	110
325	2	25	17	57	52	2	21	40	70				90	2.4	36	40	160	45	100	145
326	2	19	66	88	89	2	11													
342	2	27	55	75	83	2	10	20	10	20	2.2	27	60	2.5	37	40	70	63	143	209
344	2	19	100	100	100	2	6													
345	2	22	50	90	80	2	25	30		10	2.5	36				40		158	---	---
346	2	24	92	100	100	2	7													
347	2	24	89	100	100	2	14													
406	2	21	51	90	81	2	30	70	30	50	3.5	52	40	1.5	27	120	70	55	124	173
359	3	21	50	83	80	2	3						10	1.0	23		10	285	---	---
360	3	21	36	72	70	2	6	40		20	1.6	21				60		126	253	
380	3	24	99	100	100	2	16													
A-15	3	15	83	100	98	2	8													
267	1	21	19	19	21	3	8		20				70	2.6	65		90	64	146	204
403	3	19	62	46	57	3	13			10	1.5	25	20	1.5	27	10	20	149	---	---
404	3	22	62	56	57	3	25	70	30	50	3.5	53	40	1.5	27	120	70	49		
N-3	3	24	17	24	19	3	6	20	40	40	2.5	34	170	3.8	55	60	210		103	283
N-4	3	24	86	64	76	3	23											3	35	62
N-5	3	20	46	46	46	3	11			10	2.0	28	30	4.3	75	10	30	87	220	---
N-9	3	24	78	90	70	3	25			10	4.0	60				10		300	---	---
S-11	3	24	83	71	74	3	30	10		10	1.5	18	20	1.5	22	20	20	114	230	---
S-10	3	18	75	100	71	3	31													
297	2	20	48	90		4	10	10		20	1.9	21				30		161	---	---
300	2	24	50	100		4	5													
324	2	25	56	94		4	1						10	2.0	29		10	371	---	---
283	3	20	78	100		4	16													
285	3	22	83	100		4	16													
289	3	23	45	91		4	5													
361	3	22	83	100		4	3													
362	3	25	54	100		4	--													
363	3	26	45	100		4	1													
364	3	26	50	100		4	1													
373	3	21	75	100		4	5													
374	3	19	80	100		4	3													

Table 6.c.3 continued.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
375	3	23	80	100		4	6													
376	3	26	100	100		4	5													
382	3	23	61	85		4	2						20	1.3	21		20	269	---	---
N-6	3	25	40	76		4	11	150	10	20	1.0	14	10	1.0	15	170	20	63	111	150
A-16	3	30	71	100		4	5													
Z-20	3	26	58	100		4	6		20	20	0.8	0				20	20	130	245	---

is a summary of tree kill and slash cover rates stratified by control method.

Table 6.c.4. Kill and slash summary by treatment

Control method	Average tree kill	Average slash cover
Chained one way	70%	10%
Chained two ways	83%	13%
Cabled	57%	19%
Burned	96%	6%

The data presented above are quite general. Variation around the mean indicated that these averages could have resulted from "chance," rather than from significant associations. The one treatment method that did indicate a significant difference was burning; tree kill was quite high and slash cover was also considerably lower.

As noted above, there are references in the literature concerning the detrimental effects of slash cover on forage production; however, the exact association is still unknown. For discussion see section 7.d.

Figures 6.c.8.a and 6.c.8.b show two sites that have considerable slash cover. The photos also demonstrate the ability of tree crown slash to remain intact for a considerable period of time. The general relationship of intact slash to forage utilization is also imperfectly known. Many instances were noted where forage, protected by crown slash, appeared non-utilized. Future studies might be designed to consider the effect of slash on livestock movement as well as to study the rate of tree re-establishment by seed from mature trees.

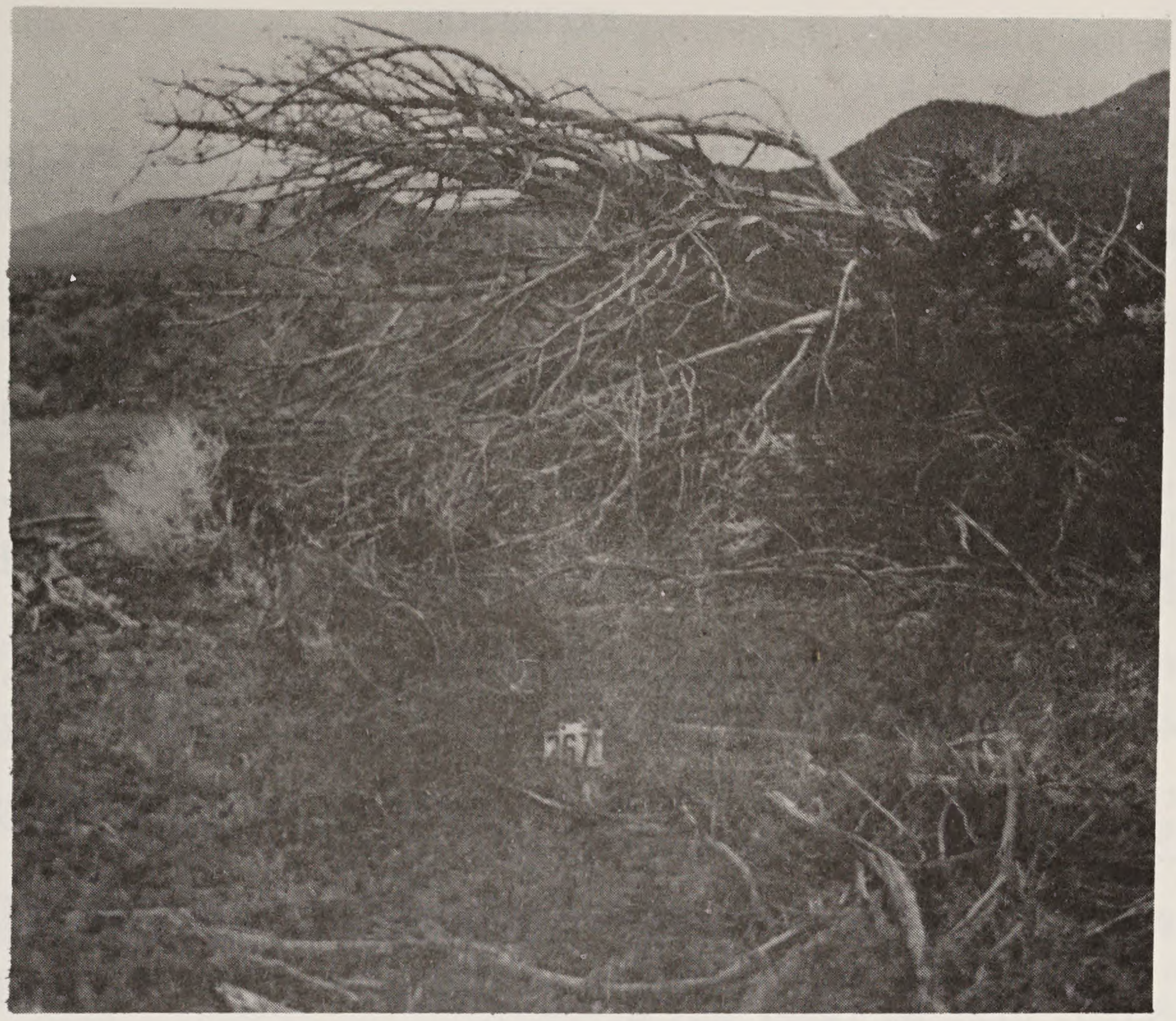


Figure 6.c.8a.
Intact tree crown slash & protected forage
8% slash cover (Initial control 1959)

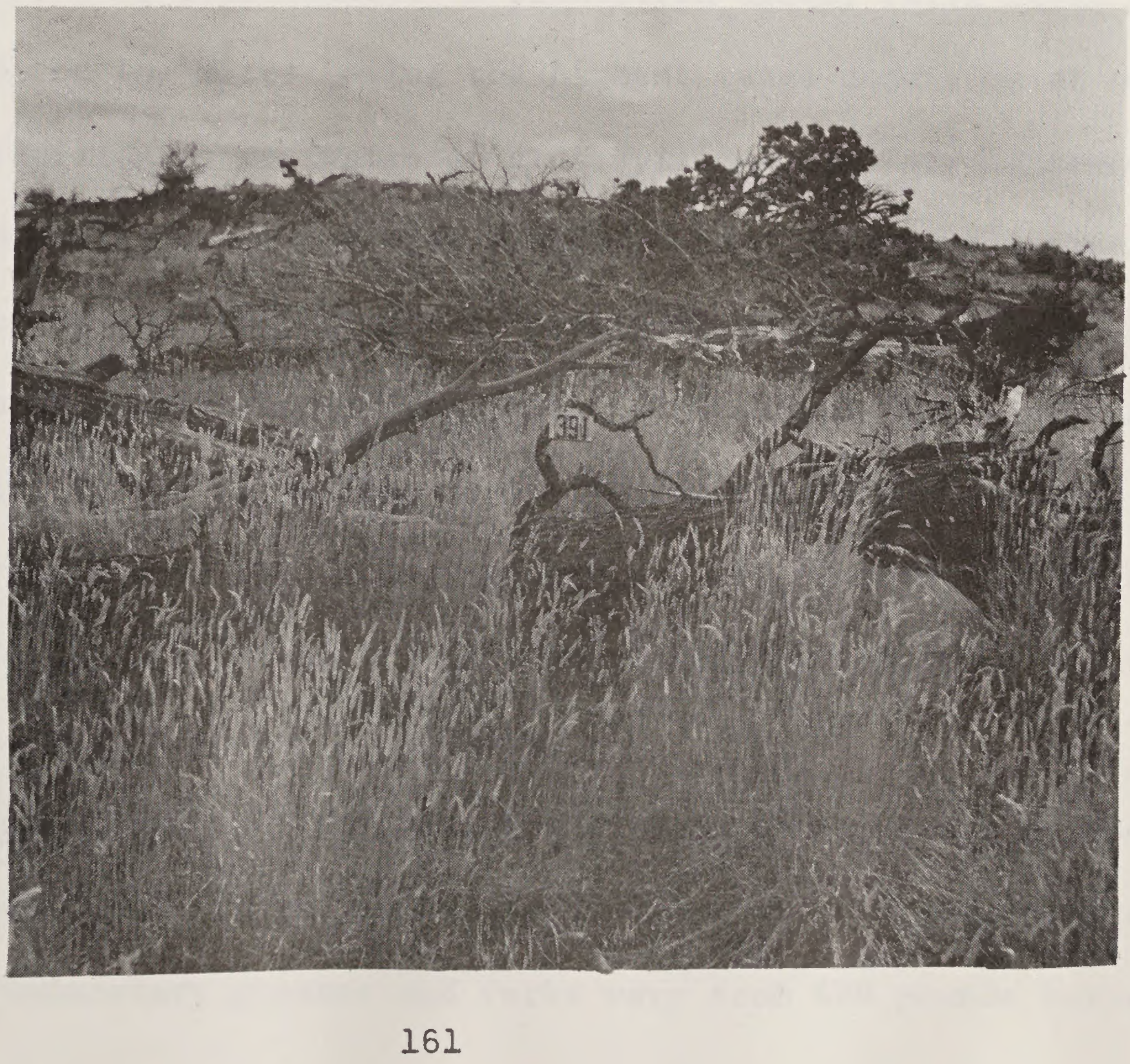


Figure 6.c.8b.
Intact tree crown slash & protected forage
28% slash cover (Initial control 1956)

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7. RANGE EVALUATION OF PINYON-JUNIPER CONVERSIONS

Grazing by domestic livestock and wildlife has been the most important use made of the pinyon-juniper type; a primary question, therefore, is how to improve grazing conditions. All intelligent decisions about the worth of converting woodlands stands to grass require evaluation of understory production potentials.

Given the wide climatic and edaphic variation in the five state area, inadequate knowledge of grazing histories, and a near absence of sites that express site potentials, range managers are apt to conclude that it is unusually difficult to predict future benefits from grazing management alone. However, one relationship stands out throughout the woodland type: understory production (especially grass production) is inversely proportional to an increase in percent of tree canopy. A production-canopy curve based upon grass production on the sites having the highest range condition at various canopy levels facilitates estimates of grass yield potentials achievable through management of particular tree stands. Since current understory production and percent of tree canopy are readily ascertained, it is a straightforward task to make comparisons with potential yields. If the potentials are great enough, it may be decided that tree control is unnecessary. Greatest increases in grass production following control will be obtained where trees are thickest, for such woodland stands have relatively the least amounts of existing forage, regardless of management.

Arnold *et al*. [1964] substantiate the inverse relationship between percent of tree canopy and forage yield. In northern and central Arizona, air dry weights of understory grasses and forbs vary from 620 pounds herbage per acre, where there's an absence of canopy intercepts, to 40 and 65 percent less with 10 and 30 percent canopy intercepts. On transects with a 50 percent intercept, the herbage yield of grasses and forbs was 82 percent less than yields free of tree influence. Using data from the Apache reservation, Arnold and Shroeder [1955] found that the relationship of herbage yields to the number of trees per acre took the same inverse form. Air dry herbage under little or no tree cover was approximately 600-700 pounds per acre, but leveled off below 100 pounds when densities reached 400-500 trees per acre.

An individual tree influences both herbage production in pounds of forage and composition of species far beyond its canopy. Arnold [1964] measured this influence from a 19 foot juniper tree and found a sizable area immediately beyond the competition of roothairs from the long laterial roots. As the microclimate changes with distance from the tree stem, there is a change in species composition. More tree rootlets grow in the openings than directly under tree crowns. They may literally fill the surface soil in the openings of fairly dense stands of trees [Plummer, 1958].

7.a. Herbage Production - Percent Tree Canopy Relationships -- H. E. Isaacson

Figures 7.a.1, 7.a.2, and 7.a.3 show the relationship of maximum grass production to percent canopy of pinyon and juniper by ecological province, Escalante-Sevier, La Sal, and Coronado. Site data used for these curves are those reflecting the highest range conditions observed in each province. The situations depicted should not be confused with ultimate potential of a site, for these curves do not reflect conditions that may be found in relict areas.

7.b. Bunch Grass--Short Grass: Relationship to Tree Cover -- H. E. Isaacson

Short grasses such as blue grama and galleta grass were never observed growing in the litter directly beneath trees (Figure 7.b.1).

Blue grama, Bouteloua gracilis, seems to be particularly affected by

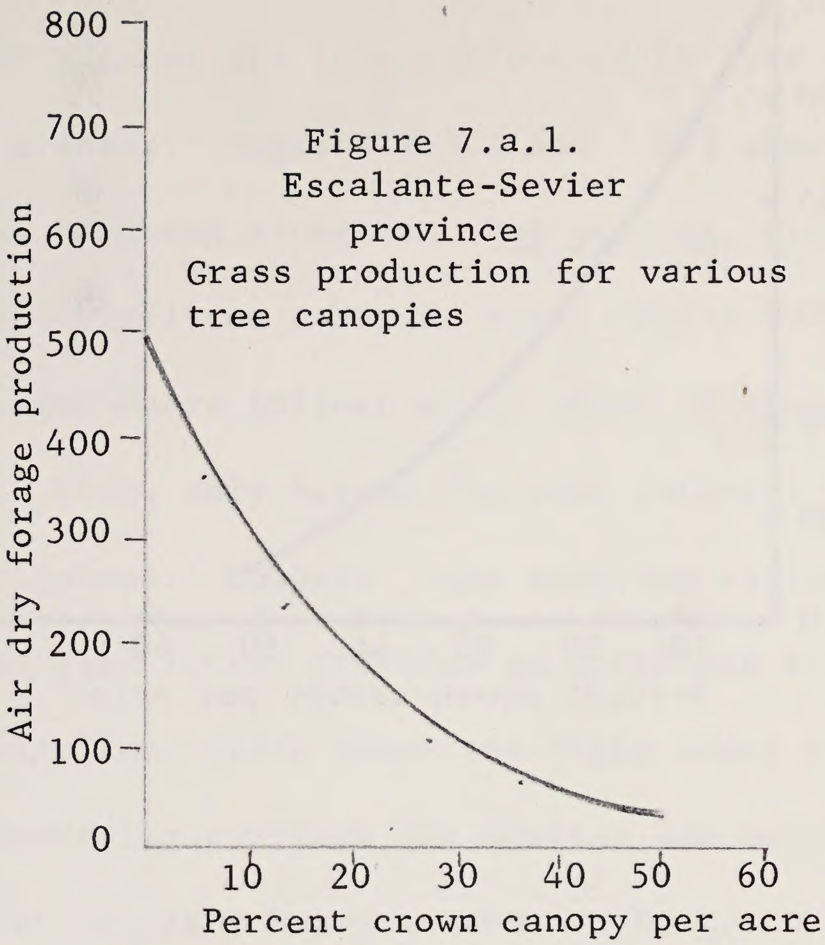


Figure 7.a.1.
Escalante-Sevier
province
Grass production for various
tree canopies

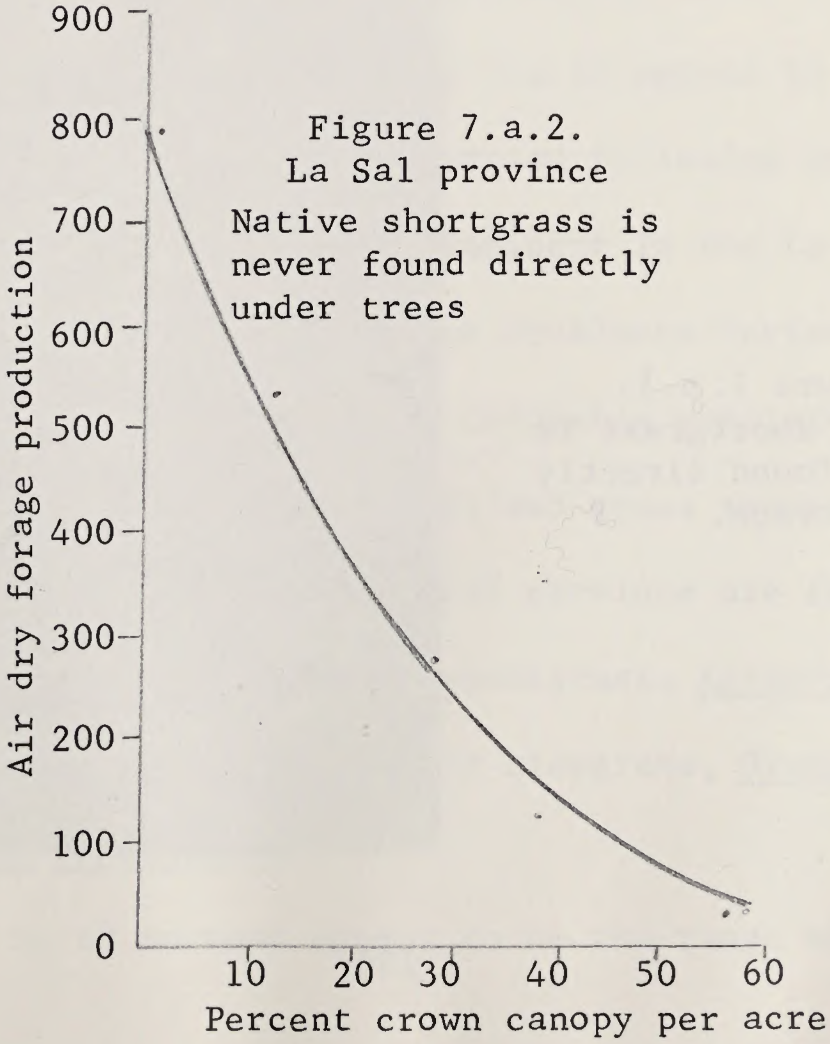


Figure 7.a.2.
La Sal province
Native shortgrass is
never found directly
under trees

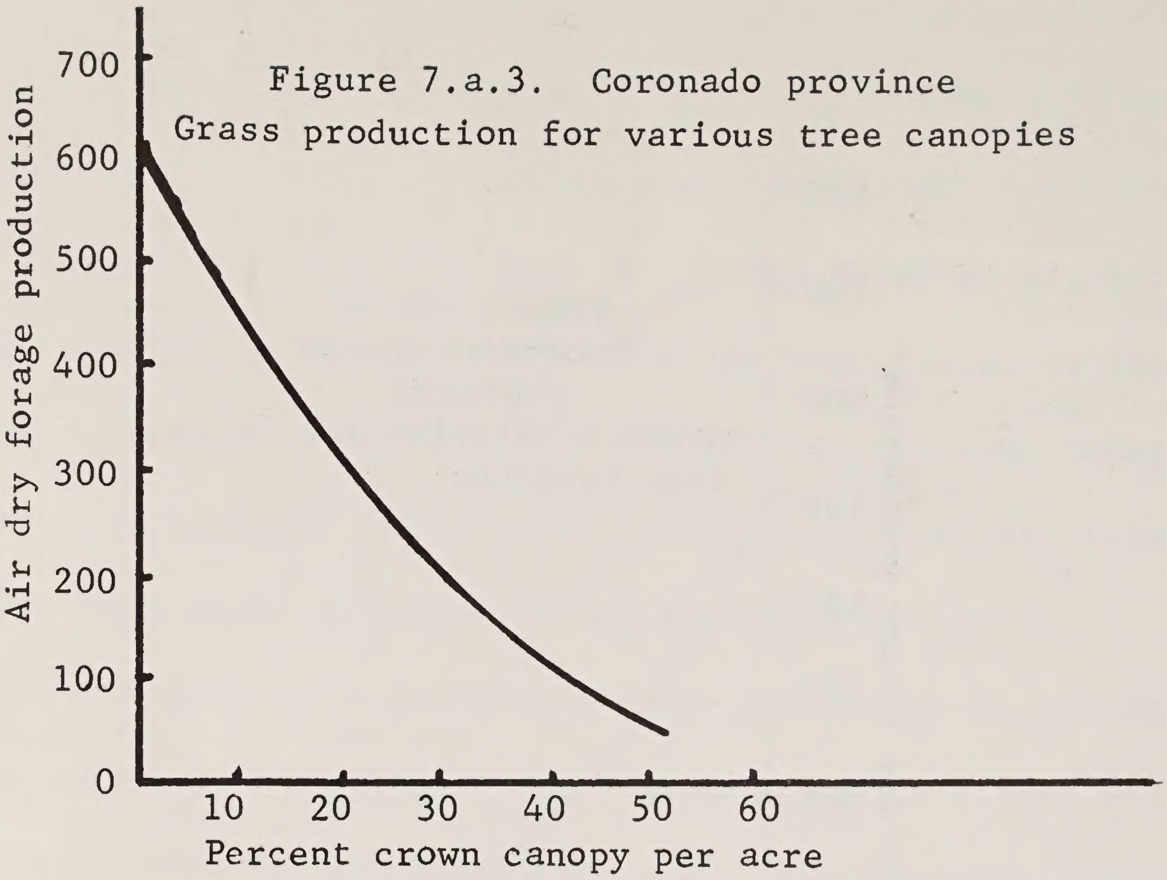
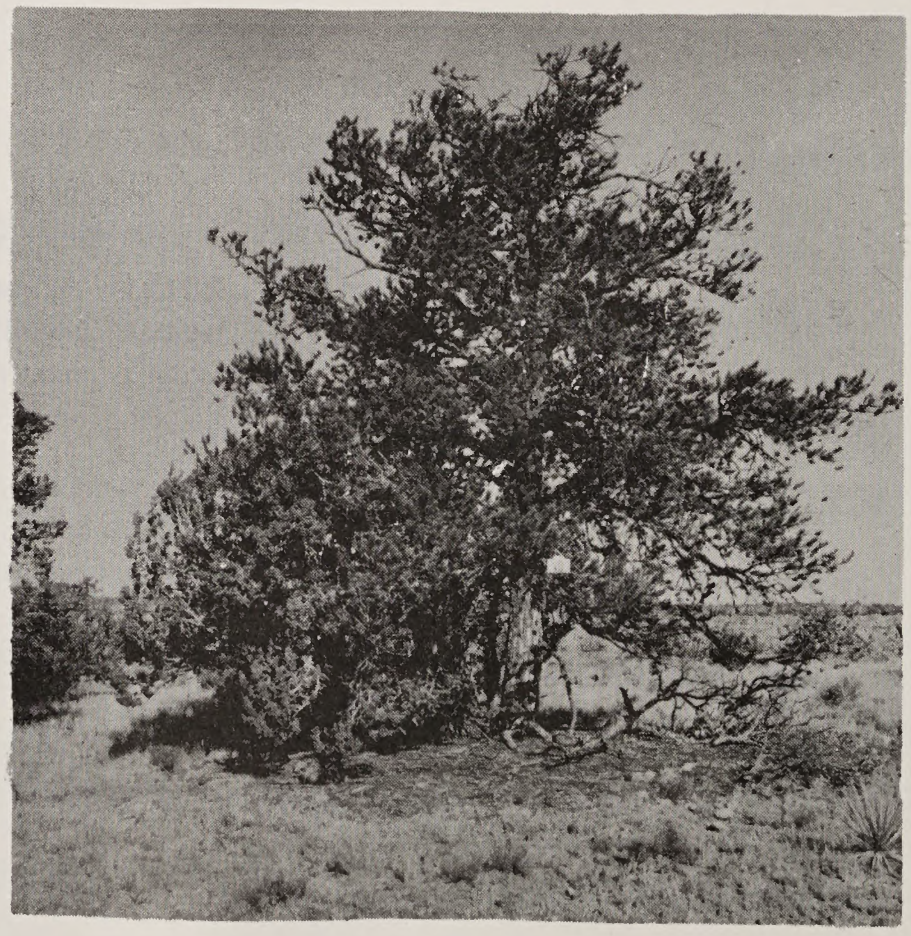


Figure 7.a.3. Coronado province
Grass production for various tree canopies

Figure 7.b.1.
Native shortgrass is never found directly under trees.



shading [Johnson, 1962] and is seldom found under plants with dense canopies. Some grasses, such as mutton grass, Poa fendleriana, (a bunch grass) are often found only under trees. Indeed, the present study confirms the notion that in general bunch grasses are less influenced by tree canopy than are short (sod-forming) grasses. Figures 7.b.2 and 7.b.3 show squirrel tail, Sitanian hystrix, and Sandberg bluegrass, Poa secunda, growing in 4 and 2 inches of litter respectively on a Nevada site. While it is true that individual plants lack vigor where influenced by shade or tree roots, they still maintain themselves. Thus, only beyond the tree laterial root zone, in open stands, are plants vigorous. However, take away the influence of a live, competitive tree, and leaf litter provides an excellent site for bunchgrass. Figure 7.b.4 shows excellent grass cover and vigor under a dead pinyon.

In the Escalante-Sevier province the species are mainly bunchgrasses. Grass production is seldom very heavy because major grass species left are squirrel tail, Sitanian hystrix, and Sandberg bluegrass, Poa secunda, neither of which attains much stature. Bluebunch wheatgrass and Idaho fescue, higher producers, are often only a remnant in the composition.

Canopies of 20 to 50 percent (Figure 7.a.1) appear to set the range of consideration for maximum increased production following eradication treatment.

Bunch grass species are also more prominent in the La Sal province, but generally production is higher than in the Escalante-Sevier province. The reason is probably a combination of more favorable precipitation distribution (early spring and mid-summer high periods) and grass species found in the woodland type. Major species in the La Sal province are fairly high producing bunchgrasses and consist of: bluebunch wheatgrass, Agropyron spicatum, beardless wheat grass, Agropyron inerme, Indian ricegrass, Oryzopsis hymenaides, and mutton grass, Poa fendleriana.

Canopies of 30 to 60 percent appear to be the range where greatest

Figure 7.b.2.
Squirreltail growing in 4 inches of litter on a Nevada pinyon-juniper site.

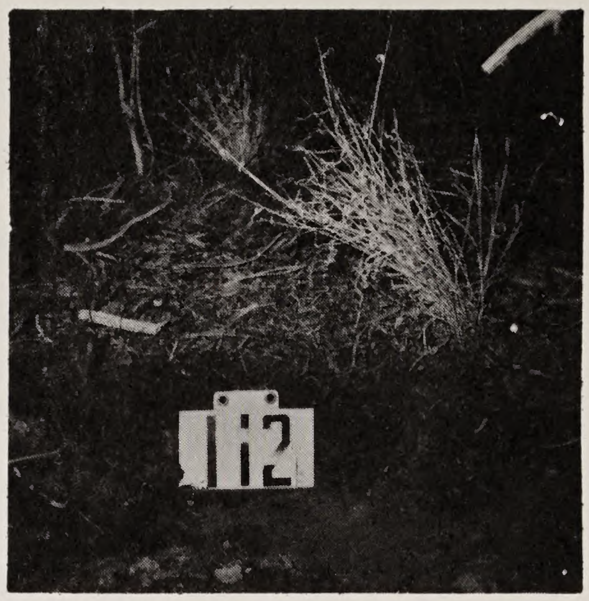


Figure 7.b.3.
Sandberg bluegrass growing in 2 inches of litter on a Nevada pinyon-juniper site.

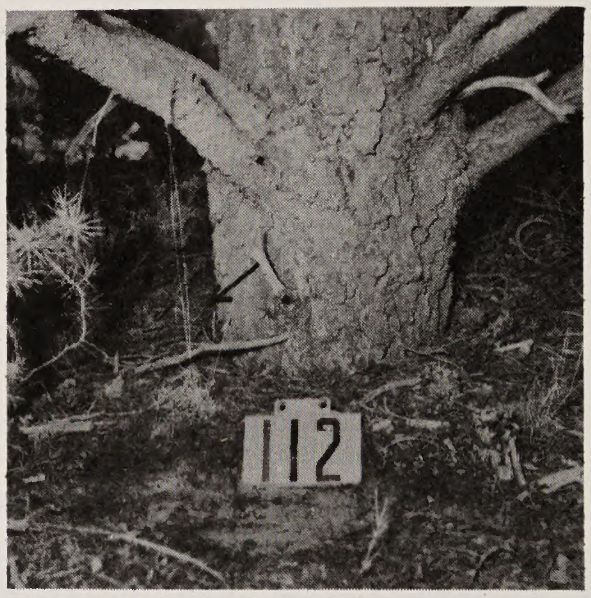
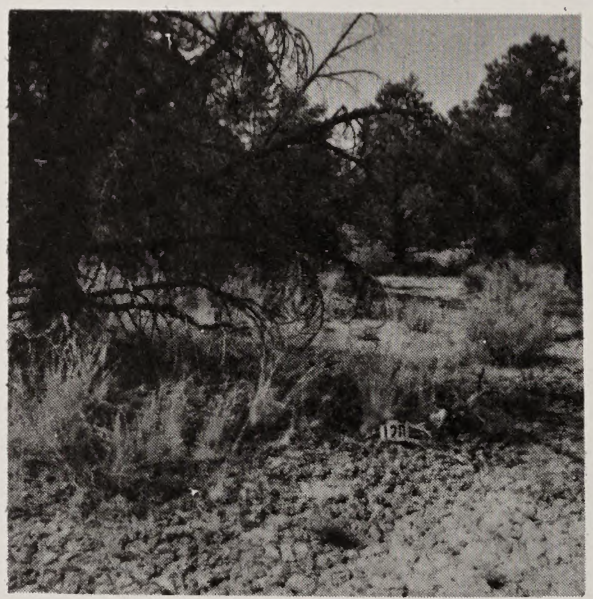


Figure 7.b.4.
Native bunchgrass looks vigorous growing in litter under a dead pinyon.



increases in production can be obtained through some form of eradication treatment of the trees (Figure 7.a.2).

The most outstanding characteristic of the Coronado province in terms of understory growth is the universal cover of grass, especially blue grama (Boutelava gracilis). Even when abused, sites sustain fairly good grass density and total grass production is high. However, the leaves of the plants seldom grow very tall so usable forage for livestock is reduced, even granting high density.

Maximum improvement through manipulation of the site appears to be in canopies from 30 to 50 percent (Figure 7.a.3).

Discussion-- Apparently within the true pinyon-juniper woodland, understory vegetative production was never very heavy. Even where protected from livestock grazing, plants are not robust where they compete with the trees. Once canopy percentages get in the neighborhood of 25 percent, most of the area between trees must be affected by tree roots or canopy shade. Plants facing this type of competition will deteriorate rapidly from a combination of climatic stress, grazing, and ever increasing tree competition. Once the understory resource has been depleted, improvements through grazing management practices will probably be imperceptive. Only in open stands were tree competition is low and understory seed stock still present, will response to management be visible in the short run.

7.c. Variation in Grass Production Associated with Conversion Methods --
H. E. Isaacson

This portion of the study provides site qualification measurements that will aid in selecting woodland sites that have the potential for successful conversion to grass.

Tree removal treatments varied greatly; they ran the gamut of dozing individual trees to chaining trees with heavy anchor chains and windrowing slash with bulldozers. Grass planting techniques were confined to broadcasting seed before or after tree removal or drilling seed on cleared areas. To simplify measuring production benefits from treatments and to provide a suitable sample size, all combinations were categorized into three major site manipulation practices:

1. Remove tree competition only.
2. Broadcast introduced grass seed and remove tree competition.
3. Chain or cable trees, windrow slash and drill introduced grass seed.

Removing Tree Competition Only-- This treatment shows less dramatic change than the other two treatments. All mechanical tree killing practices are included in the sample (bulldozing, cabling either once or twice and chaining once or twice).

The bulldozing technique was used mainly on the so-called tree invasion sites and resulting tree kill was high, only seedlings were missed.

Chaining either single or double killed most trees with a stem diameter of 3 inches or larger at one foot height. Trees from 3 to 5 inches diameter may survive cabling. As slash builds up from greater tree stand densities, kill of younger trees drops off. Pulling trees over will have a long-term influence only if the tree kill is high. Old, fairly even-aged stands will be best for cabling or chaining. Any stand with a lot of saplings requires additional treatment for lasting benefits. Percent kill was high enough on projects visited so that production potentials were probably not affected by the remaining live trees.

The rate of increase in native herbage yields following juniper control treatments in Arizona was indicated through chronological evaluation made by Arnold and Schroeder [1955]. Areas that had been cleared for two growing seasons produced an average of 82 pounds of herbage per acre more than areas cleared for one growing season. After eight seasons, the average increase in herbage yield tapered off at a total production level of about 650 to 700 air-dry pounds per acre. Arnold et al. [1964] conclude that maximum production following tree removal occurs 5 to 10 years after control and maximum production in northern Arizona can be expected at around 700 pounds air-dry herbage per acre.

Tree control without reseeding was not used extensively in the Escalante-Sevier and La Sal provinces. Where employed the highest increases in native grass production were observed from bunchgrass understory but generally results were eratic. Certain tremendous increases, from 150 pounds of air-dry grass to 850 pounds, occurred where there was an excellent stand of good native grass species (Indian ricegrass, bluebunch wheatgrass, or Mutton grass) under the trees. Combinations of these species common to their provinces made up 40 to 50 percent of the understory composition and were uniformly distributed throughout the woodland stand. The number of observations of this practice in provinces 1 and 2 were too few to allow data analysis. Tables 7.c.1, 7.c.4, and 7.c.7 show whether or not the treatment produced a significant increase in grass production and basal area for each province.

Tree control only is by far the most common treatment in the Coronado province. There are many more projects of this type than the 40 that were visited.

Broadcasting Grass Seed and Removing Tree Competition-- When proper sites are selected, this combination of treatment and reseeding is very effective. Grouped here are projects cabled or chained (single or double) before or after grass seed broadcasting, (generally from aircraft). Evaluation of seeding results is not as simple as in the case of the other two major combinations. Introduced grass establishment is seldom uniform due to the presence of slash, lack of uniformity of seed distribution and competition of native plants. Plots were located to reflect average conditions on as uniform areas as possible. The grass species planted was mainly crested wheatgrass; projects where other species were planted are footnoted in the tables and figures.

In both the Escalante-Sevier and Coronado provinces this treatment did not consistently show a significant increase in seeded species production over the native production on the comparison site, so there were too few observations for each of these provinces to allow statistical analysis. Tables 7.c.2, 7.c.5, and 7.c.8 show if significant increases in grass production and basal area followed this type of treatment in each province.

The high degree of success from broadcast seeding in the La Sal province is of great interest, particularly since the treatment is much less expensive than windrowing slash before drilling grass seed.

Chain or Cable Trees, Windrow Slash and Drill Grass Seed-- This is the ultimate seeding practice in the pinyon-juniper type; every project visited with this treatment was a success. There is greater latitude in site choices if this treatment is used. Grass production on a given site is more uniform and usable surface area also is greater. Knowledge of important site factors renders results from this type project fairly predictable. Each site reflects a different environmental complex with different productive potential. Eckert *et al.* [1961] measured responses of *Agropyron cristatum* and *Agropyron desertorum* at three different sites in eastern Nevada and found grass production was consistently different over a period of 17 years. Soil profile characteristics and slope appeared to explain a great deal of the variation in grass production. Greatest production was found on a deep profile with a low gravel content receiving additional moisture from runoff of steeper slopes.

In the southwest, Reynolds and Springfield [1953] observed potential production of crested wheatgrass herbage varied widely with growing conditions, mainly with differences in precipitation. On 11 sites in three vegetative types, Ponderosa pine, big sagebrush, and pinyon-juniper, air-dry herbage production increased as precipitation increased within the same vegetative type. However, a precipitation range of 14 to 17 inches in the sagebrush type produced as much herbage as 17 to 24 inches in the Ponderosa pine type. Production in the pinyon-juniper type in 1949 was as follows:

Location	Elevation	Precipitation	Air-dry Herbage Production
Glorieta Mesa, N. M.	7,380 ft.	16 in.	800 lbs/acre
Dog Knobs, Arizona	6,400 ft.	15 in.	640 lbs/acre
Corona, N. M.	6,670 ft.	15 in.	520 lbs/acre

Production in the pinyon-juniper type was much lower than the other types.

Too few seeded projects of this nature were available in the La Sal and Coronado provinces to develop an analysis of how site factors contribute to resulting grass production. Where observed in the La Sal province, the technique was always successful, and resulting grass production was significantly greater than broadcasting seed when the two practices were carried out on the same site (Table 7.c.10).

Seeding grass species, especially introduced species, requires a unique site in the Coronado province, even if drilled. Total average annual precipitation requirements appear to be 15 inches or higher on sites that receive fairly heavy late winter precipitation [Springfield, 1965]. Results from this treatment (Tables 7.c.3, 7.c.6, and 7.c.9) from all the provinces were tested to see if the treatment produced a significant increase in grass production and grass basal area.

Table 7.c.1. Projects in the Escalante-Sevier province that were chained but not seeded

Study No.	Project No.	Name	Treatment	Year treated	Control		Treated grass production	
					Grass lbs. dry wt. acre	Basal area %	Native lbs/ac.	Basal area %
260	near Boulter	Wildfire	Wildfire***	1956	39	1.7	432**	9.9**
267	U 3 & 10 433	Indian Creek	Cabled twice	1959	7	0.6	156**	7.1**
388A	N 1 R-442	Spruce Mt. 6,700 ft.	Chain once	1964	4	0.3	136	2.8*
388B	N 1 R-442	Spruce Mts. 6,900 ft.	Chain once	1964	130	4.8	856**	8.7*

***Study No. 260 is a woodland site that was burned off with resulting native grass recovery.

**Significantly different native grass production at the 0.01 level from control.

*Significantly different native grass production at the 0.05 level from the control (adjacent untreated area).

Table 7.c.2. Projects in the Escalante-Sevier province that were broadcast with introduced species and chained

Study No.	Project No.	Name	Treatment	Year treated	Control		Treated grass production			
					Grass dry wt. lbs/ac.	Basal area %	Seeded lbs/ac.	Basal area %	Native lbs/ac.	Basal area %
256C	U 2-175	Govt. Creek	Chain once and broadcast seed	1960	21	0.9	362**	8.6**	72*	3.1*
258B	U 2-R-12	Ekker	Chain once and broadcast seed	1962	116	3.1	430**	8.4**	62	1.5
270	U 4-R-75	Pine Valley	Chain twice, drilled, (mostly unseeded)	1962	13	1.1	115**	1.8	282**	4.7**
275	U 4-R-1	Willow Spring	Chain twice and broadcast seed	1961	18	0.7	344**	8.2**	38	1.1
276	U 4-466	Perrywell	Chain once and broadcast seed	1962	101	4.9	0	0.0	472**	6.0
277	N 5-R-7	Taylor	Chain once and broadcast seed	1961	17	1.1	218**	4.5**	79*	2.6
278	N 5-477	Cave Springs	Chain once and broadcast seed	1958	1	0.1	12	0.3	6	0.2
280	N 5-478	Enterprise	Chain once and broadcast seed	New	4	0.3			140**	2.6**
281	N 5-R-11	Mahogany Knoll	Chain once and broadcast seed	1961	5	0.4	7	0.3	39	1.2
377	U 3-R-50	Cedar Cove	Chain twice and broadcast seed	1962						
410	N-5-543	Enterprise	Chain once and broadcast seed	1960	46	1.8	606**	6.1	19	0.4

**Significantly different grass production, native and seeded species, at the 0.01 level from the control.

*Significantly different grass production, native and seeded species, at the 0.05 level from the control (adjacent untreated area).

Table 7.c.3. Projects in the Escalante-Sevier province that were chained, cleared, and drilled

Study No.	Project No.	Name	Treatment	Year treated	Control		Treated grass production	
					Grass dry wt. lbs/acre	Basal area %	Seeded lbs.	Basal area %
254A	Expt. Plot	Tintic Valley	Chain, windrow, and drill		11	0.8	1198**[a]	10.9**
254B	Expt. Plot	Tintic Valley	Chain, windrow, and drill		11	0.8	845**	16.9**
254C	Expt. Plot	Tintic Valley	Chain, windrow, and drill		11	0.8	1040**	15.0**
255	U 10 APW 72	Birch Canyon	Chain, windrow, and drill	1963	21	0.8	1250**	16.3**
256	U 2 R-156	Govt. Creek	Chain, windrow, and drill	1960	21	0.9	721**	16.7**
258C	U 2 R-12	Ekker	Chain, windrow, and drill	1962	116	3.1	452**	6.9**
259	U 2	Boulter Area	Chain, windrow, and drill		24	1.1	921**	16.4**
261	U 3 & 10 413	Porcupine 6,400 ft.	Chain, windrow, and drill	1958	5	0.3	1169**	14.7**
262	U 3 & 10 413	Porcupine 6,100 ft.	Dozing, windrow, and drill	1956	31	1.6	576**	13.3**
263	U 3 & 10 468	Shag Hallow	Chain, windrow, and drill	1961	19	1.0	1544**	21.2**
266C	U 3 & 10 430	Indian Creek	Chain, windrow, and drill	1959	32	1.1	1147**	12.1**
269	U 3 & 10 416	Jockeys	Chain and drill twice, windrow	1958	5	0.3	1189**	19.5**
273	U 3 & 10 437	Sheep Creek	Chain, windrow, and drill	1960	1	0.1	1776**[b]	19.5**
274	U 3 & 10 458	Pinto Creek	Chain, windrow, and drill	1961	4	0.3	1107**	12.2**
275C	U 4-R-1	Willow Spring	Chain, windrow, and drill	1962	18	0.7	1044**	15.1**
279	N 5-478	Enterprise	Chain, windrow, and drill	1963	46	1.8	854**	10.5**

Table 7.c.3 continued

Study No.	Project No.	Name	Treatment	Year treated	Control		Treated grass production	
					Grass dry wt. lbs/ac.	Basal area %	Seeded lbs.	Basal area %
282	U 4-485	Little Creek Mt.	Chain, windrow, and drill	1961	5	0.2	647**	7.1**
378	U 3-R-55	Bucket Ranch	Chain, windrow, and drill	1963	30	0.2	911	18.9
385	N-5R-6	Oak Springs	Chain, windrow, and drill	1961	3	0.2	919**	18.9**
379	U 4-R-187	Arrowhead	Chain, windrow, and drill	1962-64	4	0.3	1602**[a]	13.9**
386	N-5-432	Beaver Dam Flat	Chain, windrow, and drill	1961	17	1.0	711**	8.8**

[a] Seeded species intermediate wheatgrass.

[b] Mixture of crested and intermediate wheatgrass.

**Significantly different grass production at the 0.01 level from the control.

*Significantly different grass production at the 0.05 level from the control (adjacent untreated area).

Table 7.c.4. Projects in the La Sal province that were chained with no seeding treatment

Study No.	Project No.	Name	Treatment	Year treated	Control		Treated grass production	
					Grass lbs. dry wt/acre	Basal area %	Native lbs/ac.	Basal area %
319	C 1-499	Craig	Chain once	1958	108	3.6	546**	8.0**
320	C 1 510-512	Craig	Chain once	1959	275	5.3	507**	8.7*
321	C 1 510-512	Craig	Chain once	1959	7	0.3	31	0.8
324	U 8-R77	Diamond Mts.	Wildfire - portion[b]	Unknown	45	2.7	750**	19.6**
325	U 8-R-76	Brush Creek	Chain twice	1963	87[a]	5.6	588**	15.2**
344	C 3-R78	Monitor Mesa	Chain twice	1959	21	0.9	139**	4.6**
398	U 6-R-308	Shay Mesa	Chain twice	1959	74[a]	3.1	597	13.0
296	U-7-R-137	Pinnacle	Chain twice and broadcast	1962	80[a]	4.9	1393**	16.5**

[a] No evidence of aerial seeding.

[b] Study No. 324 resulted from a wildfire.

**Significantly different grass production, native and seeded species, at the 0.01 level from the control.

*Significantly different grass production, native and seeded species, at the 0.05 level from the control (adjacent untreated area).

Table 7.c.5. Projects in the La Sal province that were broadcast with introduced grass seed and chained

Study No.	Project No.	Name	Treatment	Year treated	Control		Treated grass production			
					Grass dry wt. lbs/ac.	Basal area%	Seeded lbs/ac.	Basal area%	Native lbs/ac.	Basal area %
293	U 7-R 89	Huntington Creek	Chain twice and broadcast	1961	0	0	733**[a]	8.5**	100	2.0
297	U 6 316	Redd Ranches	Chain once and broadcast	1960& 1962	25	0.9	566**	6.6**	2	0.1
299	U 6 308	Shay Mesa	Chain twice and broadcast	1959	74	3.1	402**	10.0		
300	U 6 324 area	Peter's Point - Manti-LaSal N.F.	Chain once and broadcast	1960	104	5.0	389**	4.6	106	1.6
301	U 6 324	Peter's Point	Chain once and broadcast	New	31	1.8	874**	14.8**	30	0.8
302	U 6 area	Private Project	Chain once and broadcast	Old	5	0.3	771**	7.9**	61	0.9
304	U 6 R 66	Bug Point	Chain twice and broadcast	1963	2	0.1	671**	12.5**	335**	4.8**
305	U 6 292	Table Top	Chain twice and broadcast	1958	8	0.6	370**	4.0**	207**	5.0**
306	U 6-R 18	Brushy Basin	Chain twice and broadcast	1962	32	2.4	871**	11.0**	227**	4.5
307	U 6-R-3	Alkali Point	Chain twice and broadcast	1961	2	0.1	1108**	11.8**	64*	1.1**
330	U 11	Sheep Flat	Chain once and broadcast	1958	19	0.5	842**	10.5**	185**	3.3*
333	C 4-R 278	Hovenweep	Chain once and broadcast	1963	41	2.3	0	0	240**	5.5*
334	C 4-R 236	Helper	Chain once and broadcast	1963	30	1.1	24	0.4	142**	6.6*
335	C 4-R 158	Green	Chain once and broadcast	1962	8	0.4	946**	11.1**	24	0.7
336	C 4-R 235	Heller	Chain once and broadcast	1963	127	5.1	193	1.8	451**	7.8*

Table 7.c.5 continued.

Study No.	Project No.	Name	Treatment	Year treated	Control		Treated grass production			
					Grass dry wt./ lbs/ac.	Basal area%	Seeded lbs/ac.	Basal area%	Native lbs/ac.	Basal area%
337	C 4-R 159	Grand	Chain once and broadcast	1962	257	11.3	710**	5.8	338	4.9
338	C 4-R 176	Grammer	Chain once and broadcast	1962	111	4.4	383**[a]	5.9	281*	7.9
339	C 3-R 138	Garison	Chain once and broadcast	1963	2	0.2	0	0	35	1.0
340	C 3 R-137	Paxton	Chain once and broadcast	1963	23	1.1	30[a]	0.3	436**	11.4**
342	C 3 R-346	Roubideau #2	Chain twice and broadcast	1964	49	2.7	1069**	9.0**	138	2.8
343	C 3 R 78	Roubideau #1	Chain once and broadcast	1961	79	3.5	402**	6.4**	82	2.5
345B	C 3 R 313	Davis	Chain once and broadcast	1964	29	1.2	154**	4.2**	93*	3.0
346	C 3 R 283	Mesa	Chain twice and broadcast	1958	132	5.6	498**	7.3	112	5.1
348	C 7-R-7	Timber Ridge B	Chain twice and broadcast	1959	41	2.2	880**	10.3**	54	0.9
391C	U 6-261	Dark Canyon #1	Chain twice and broadcast	1956	57	2.7	1027**	11.5**	10	0.4
391B	U 6-277	Dark Canyon #2	Chain once and broadcast	1957	57	2.7	876**	14.3**	9	0.4
406	U 6-279	Pearson Point	Chain twice and broadcast	1960	68	3.0	562**	5.4*	129	2.7
326	U 11	Mackelprange	Chain, broadcast, and chain	1963	20	0.7	276**	8.2**	0	0
330	U 11	Sheep Flat Juniper	Chain once and broadcast	1958	19	0.5	842**	10.5**	158**	3.3*
318	U 6-R-4	Cyclone Flats	Chain twice and broadcast	1961	5	0.2	899**	10.5**	0	0
322	U 8	Pine Springs F. and G.	Chain twice and broadcast	1962	42	2.6	575**[a]	6.1**	368**	6.7**

Table 7.c.5 continued.

Study No.	Project No.	Name	Treatment	Year treated	Control		Treated grass production			
					Grass dry wt./ lbs/ac.	Basal area%	Seeded lbs/ac.	Basal area%	Native lbs/ac.	Basal area%
323B	U 8 R-11	Boulevard	Chain twice and broadcast	1961	5	0.2	899**	10.5**	0	0
324	U 8 R-77	Diamond Mt.	Wildlife seed - chain twice	1963	45	2.7	770**	15.7**	750**	19.6**
345C	C 3-R-278 and 277	Donnely 2	Chain once and broadcast	1963	--	----	864	11.9	---	--

[a] Other species in seeded grass production beside crested wheatgrass.

**Significantly different grass production, native and seeded species, at the 0.01 level from the control.

*Significantly different grass production, native and seeded species, at the 0.05 level from the control (adjacent untreated area).

Table 7.c.6. Projects in the La Sal province that were chained, cleared and drilled with introduced grass seed

Study No.	Project No.	Name	Treatment	Year treated	Control		Treated grass production	
					Grass lbs/dry wt./ac.	Basal area%	Seeded lbs/ac.	Basal area%
294	U 5-435	Airplane Sprs.	Dozing, windrow and drill	1957	5	0.3	1049**	19.7**
295	U 5-69	Praetor Slopes	Chain twice, windrow and drill	1963	19	1.0	981**	16.5**
303	U 6-R-66	Bug Point	Chain twice, windrow & drill	1963	2	0.1	671**	12.5**
327	U 11 R-42	Vermillion	Chain, windrow, and drill	1963	24	0.8	572**	19.5**
328	U 11 R-29	Airport Flat	Chain, windrow, and drill	1963	99	3.8	786**	12.4**

**Significantly different grass production at the 0.01 level from the control.

*Significantly different grass production at the 0.05 level from the control (adjacent untreated area).

Table 7.c.7. Projects in the Coronado province that were chained or cabled with no seeding treatment

Study No.	Project No.	Name	Treatment	Year treated	Control		Treated grass production	
					Grass dry wt. lbs/ac.	Basal area%	Native lbs./ac.	Basal area%
284	A 1-402	T. Jensen	Chain once	1960	186	10.7	578**	18.0**
286	A 1-374	Poverty Mountain	Chain once	1958	29	1.9	165**	8.0**
288	A 1-369	Upper Sullivan	Dozing	1957	100	8.2	151	7.8
289	A 1-374	Poverty Mountain	Chain once	1960	185	9.0	346**	12.8*
310	NM 7-R	Robb Brothers	Cable once***	1962	63	3.6	344**	8.7**
311	NM 7-X-152	Sowers	Chain once	1958	82	3.3	272*	7.9
314	NM 7-R-93	Blancett	Chain once	1961	67	3.6	328**	8.3**
315	NM 7-X-364	B-lancett	Chain once	1958	25	1.3	95**	3.3
365	F.S.	Cosnino	Cable once	1959	144	9.5	430*	13.4
366	F.S.	Angell	Cable once	1957	54	3.6	326**	8.4**
373	F.S.	Mudtanks	Dozing	1956	386	16.5	514	18.2
375	F.S.	Dog Knobs	Dozing***	1959	337	16.1	629**	31.5**
376	F.S.	Smoot Lake	Dozing	1958	166	18.2	350**	24.1
380	A 1-R-459	Elmo Bundy	Chain once	1962	137	4.0	165	4.3
382	A 1-298	Bundy Trumble	Dozing	1956	79	6.5	217*	8.4
383	A 1-R-544	Hurricane Rim	Chain once	1964	72	8.1	290**	10.0
398	B.I.A.	5 Houses (Hopi) #1	Cable once***	1959	83	5.6	192*	9.1*
399	B.I.A.	Hopi #5	Cable once	1959	93	4.3	274**	9.7**
400	B.I.A.	Cedar Ridge	Cable once***	1957	115	4.7	460**	8.8
403	B.I.A.	P. Begay	Cable once***	1958	55	2.9	186*	5.9
404	B.I.A.	Eli Crank	Cable once***	1958	3	0.2	41	0.8
2 N	B.I.A.	Mike Johnson	Cable once	1957	105	4.6	348**	8.5*
3 N	B.I.A.	Henry Draper	Cable once***	1957	25	1.9	81	2.4
4 N	B.I.A.	Dick Deal	Cable once	1957	82	5.4	182	13.1
5 N	B.I.A.	Bonniface Bonnie	Cable once	1954	74	6.3	247**	12.6*
6 N	B.I.A.	Bonniface No. 2	Cable once	1958	29	2.6	220**	6.8*
7 N	B.I.A.	Bent Knee	Cable once	1957	53	5.1	274**	14.5*
8 N	B.I.A.	#37-#55 Ft. Def.	Cable once	1958	32	2.3	243*	5.4
10 S	F.S.	Linden Fence	Cable once	1963	71	7.4	238**	15.9**
11 S	F.S.	West Sundown	Cable and doze	1954	115	10.9	426**	18.1*

Table 7.c.7, continued.

Study No.	Project No.	Name	Treatment	Year treated	Control Grass dry wt. lbs/ac.	Control Basal area%	Treated grass production Native lbs/ac.	Treated grass production Basal area%
13 S	F.S.	Govt. Tanks	Dozing	1963	99	10.0	395**	11.7
14 S	F.S.	Ortega Lake	Dozing and cable	1959	171	18.8	581**	15.8
19 ZB	B.I.A.	Zuni #8	Cable once	1959	64	7.3	281**	9.0
20 Z	B.I.A.	Zuni #10	Cable once	1964	111	6.6	428**	10.0
4 H	B.I.A.	Hopi #4	Cable and chain	1960 and 1964	209	13.3	337*	11.8

***No evidence of seeding.

**Significantly different native grass production at the 0.01 level from the control.

*Significantly different native grass production at the 0.05 level from the control (adjacent untreated area).

Table 7.c.8. Projects in the Coronado province that were broadcast with grass seed and either chained, cabled, or drilled to remove the trees

Study No.	Project No.	Name	Treatment	Year treated	Control		Treated grass production			
					Grass lbs dry wt./ac.	Basal area%	Seeded lbs/ac.	Basal area%	Native lbs/ac.	Basal area%
283	A 1-279	Lost Spring Mts.	Chain twice and broadcast	1955	2	0.1	134*[a]	2.5*	50*	1.5*
285	A 1-R-33	Jensen	Chain once and broadcast	1961	69	3.6	0	0	99	4.4
290	A 1-382	Little Wolf	Chain once and broadcast	1959	1	0.1	298**[a]	3.9**	83**	1.7**
292	A 1-378		Doze, burn and broadcast	1959	23	1.2	300*	9.0*	40	2.0
309	NM 7-R-24	Myers	Chain once and broadcast	1961	3	0.2	240**	5.3**	45	0.9
312	NM 7-R-158	Pat Montoya	Chain once and broadcast	1962	51	3.5	0	0	125	6.1*
313	NM 7-R-209	Pat Montoya	Chain once and broadcast	1962	62	2.9	67	1.9	141*	3.4
316	NM 7-R-208	R. Vlibarri	Chain once and broadcast	1962	49	2.3	164*	2.7	153*	2.6*
317	NM 7-R-333	Blancett	Chain once and broadcast	1963	29	2.8	0	0	275**	5.6*
360	F.S.	Ryan Allotment	Chain, doze and broadcast	1960	76	4.7	530**	9.8*	34	1.1
361	A 1-398	Sand Hill	Chain once and broadcast	1959	74	6.6	0	0	288**	7.4
362	F.S.	Apache Maid	Cabled and pushed broadcast	1957	53	1.4	242*[b]	3.3	175*	5.2*
363	F.S.	Apache Maid	Handchop ? broadcast	1958	39	1.6	86	1.7	169**	3.5*
364	F.S.	Apache Maid	Handchop ? broadcast	1958	40	1.6	194	3.9	234**	6.4*
372	B.I.A.	Haulapai	Chain once and broadcast	1960	139	4.3	136	0.8	237**	5.0*
374	F.S.	Mud Tanks	Dozing and broadcast	1952	170	9.7	130	2.5	374	12.3

Table 7.c.8 continued.

Study No.	Project No.	Name	Treatment	Year treated	Control		Treated grass production			
					Grass lbs. dry wt./ac.	Basal area%	Seeded lbs/ac.	Basal area%	Native lbs/ac.	Basal area%
402	B.I.A.	White Mesa	Cable once and broadcast	1957	128	6.5	57	1.0	261**	8.7
1 NC	B.I.A.	Chinle #1	Chain once and broadcast	1958	174	5.7	888**[a]	5.5	550	11.9
12 S	F.S.	Dodson	Doze and broadcast	1960	110	8.4	164	1.9	345**	13.3
16 A	B.I.A.	Ft. Apache 1739#1	Doze and broadcast	1958	42	2.1	936**[a]	10.9**	64	2.3
2 H	B.I.A.	Hopi	Chained once - some seed	1962	207	8.9	0	0	515	9.7

[a] Seeded grass production a mixture of seeded species with crested wheatgrass.

[b] Seeded grass production Lovegrass.

**Significantly different grass production, native and seeded species, at the 0.01 level from the control.

*Significantly different grass production, native and seeded species, at the 0.05 level from the control (adjacent untreated area).

Table 7.c.9. Projects in the Coronado province that were cleared of all competition prior to seeding grass

Study No.	Project No.	Name	Treatment	Year treated	Control		Treated grass production	
					Grass lbs. dry wt./ac.	Basal area%	Seeded lbs/ac.	Basal area%
291	A 1-461		Chain, windrow and drill	1962	2	0.1	951**	9.6**
367	B.I.A.	Haulapai	Burn and broadcast (1954)	1953	79	4.5	1549**[a]	14.6**
368	B.I.A.	Haulapai	Burn and broadcast	1963	150	6.2	1461**	19.3**
369	B.I.A.	Haulapai	Burn and broadcast	1962	270	11.8	1275**	15.7*
370	B.I.A.	Haulapai	Burn and broadcast	1957	134	13.7	1213**[a]	16.1**
371	B.I.A.	Haulapai	Burn and broadcast	1959	89	5.4	703**	8.8

[a] Seeded grass production mainly crested wheatgrass with other seeded species.
**Significantly different grass production at the 0.01 level from the control.
*Significantly different grass production at the 0.05 level from the control (adjacent untreated area).

Table 7.c.10. Comparison of two seeding treatments, broadcast-chain and clear and drill, at the same sites

Study No.	Project No.	Year	Treatment[a]	Drilled grass production lbs./acre	Basal area%	Treatment[b]	Native & broadcast production lbs./acre	Basal area%	Difference in grass production lbs./acre	Difference in basal area %
256	U 2 R-57	1960	Chain once & broadcast	721	16.7	Chain once, windrow & drill	436	11.4	285**	5.3**
258	U 2 R-12	1962	Chain once & broadcast	452	6.9	Chain once, windrow & drill	492	9.9	---	---
275	U 4 R-1	1962	Chain once & broadcast	1044	15.1	Chain once, windrow & drill	382	9.3	662**	5.8**
312	NM 7R-158	1962	Chain once & broadcast	348	11.9	Cleared & power line seeded	176	9.6	172**	2.3
313	NM 7R-207	1962	Chain once & broadcast	447	12.7	Cleared & power line seeded	207	5.3	240**	7.4**
322	U8 Pine Springs	1962	Chain twice & broadcast	1132	11.8	Cleared along road & seeded	943	13.0	189**	---
323	U8 R-77	1961	Chain twice & broadcast	1747	16.1	Chain twice, burned & broadcast	833	13.9	914**	2.1
335	C4 R-158	1962	Chain once & broadcast	1343	19.0	Cleared along road & seeded	969	11.8	374**	7.2**
338	C4 R-176	1958	Chain once & broadcast	848	11.8	Cleared along fence & seeded	667	13.9	181**	---
345	C3 R-313	1963	Chain once & broadcast	864	11.9	Cleared, burned & drilled	247	7.2	617**	4.7**
348	C7 R-7	1960	Chain twice & broadcast	1254	16.6	Cleared, area in same seeding	934	11.2	320**	5.4**

**Difference in production significant at the 0.01 level.

[a] Treatment generally identified with job.

[b] Treatment giving higher production.

7.d. Grass Production/Site Factors by Major Conversion Treatment -- H. E. Isaacson and A. LeBaron

Multiple regression analysis was employed to relate site factors to grass production following a given control method. The control treatment most commonly employed in each province was analyzed by province. Site data from 28 chaining, windrowing, and drilling projects in the Escalante-Sevier province, 36 broadcast and chain projects in the La Sal province, and 39 cabling or chaining only projects in the Coronado Province were used. The dependent and independent variables for the three regressions are shown in Table 7.d.1. An explanational listing of these variables is found at the end of this section (Table 7.d.6).

The cross-sectional data employed in the regression analysis almost certainly exhibits multicolinearity; observations of individual variables are not truly independent. It is possible to attempt to allow for interactions among variables by combining them in different fashions (indeed linear combinations have been employed extensively in the present instance: $X_2 \cdot X_9$, $X_5 \cdot X_{10}$, etc.). Such combinations may lead to improvements in calculated coefficients of determination, but the interaction terms themselves become difficult to interpret and explain.

The interaction terms actually employed are those thought to have the strongest effect on the dependent variable in question. Choices were based on the methods employed by Hurst and Pederson [1964]. The exact interrelationships that each choice implies have not been worked out, and no interpretation will be given in this particular report.

The machine program computed regression coefficients, mean squares, error terms, and r^2's for all of the variables (as listed in Table 7.d.1) for each separate province. The variable explaining the least amount of variance was then automatically dropped and the computations were repeated.

Table 7.d.1. Dependent and independent variables used in multiple regressions by province

	Dependent variables	Dependent variables used by province		
		Escalante-Sevier	La Sal	Coronado
Y_1	Production seeded grass (drilled)	X		
Y_2	Production seeded grass (broadcast)		X	
Y_3	Production native grass			X

	Independent variables	Independent variables used by province		
		Escalante-Sevier	La Sal	Coronado
X_1	Average annual precipitation	Only used in interaction		
X_2	Depth A layer	Only used in interaction		
X_3	Depth A and B layer	X	X	X
X_4	Texture A horizon	X	X	X
X_5	Development of B horizon	X	X	X
X_6	Latitude	X	X	X
X_7	Stoniness A horizon	X	X	X
X_8	Stoniness surface	X	X	X
X_9	Pinyon site index	X	X	X
X_{10}	Juniper site index	X	X	X
X_{11}	Precipitation x depth A	X	X	X
X_{12}	Precipitation x latitude	X	X	X
X_{13}	Precipitation x stoniness A	X	X	X
X_{14}	Precipitation x stoniness surface	X	X	X
X_{15}	Precipitation x pinyon site index	X	X	X
X_{16}	Precipitation x juniper site index	X	X	X
X_{17}	Depth A_2 x stoniness surface	X	X	X
X_{18}	Depth A_2 x juniper site index	X	X	X
X_{19}	Development B x pinyon site index	X	X	X
X_{20}	Development B x juniper site index	X	X	X
X_{21}	Pinyon site index x juniper site index	X	X	X
X_{22}	Native grass production prior to treatment		X	X
X_{23}	Native grass production prior to treatment^2		X	X
X_{24}	Precipitation x grass production prior		X	X
X_{25}	Latitude x grass production prior		X	X
X_{26}	Pinyon site index x grass production prior		X	X
X_{27}	Latitude x grass production prior		X	X
	TOTALS	19	25	25

The program continued in this "step-wise" fashion until only one independent variable remained. At each "step" the coefficient of determination of the model fell until, the final, residual variable was ordinarly shown to explain 10-20 percent of the total variation in Y (grass production).

Table 7.d.2a. Partial correlations of residual variables with seeded grass production in the Escalante-Sevier province (chain, windrow, and drill)

Residual variables		R
X_3	Depth A + B horizon	.627
X_{21}	Pinyon ht. x pinyon site index	.301
X_5	Development of B horizon	.047
X_{19}	Development of B horizon x pinyon site index	.234
X_{15}	Precipitation x pinyon site index	.315
X_8	Stoniness of surface	.005
X_9	Pinyon site index	.193
X_{16}	Precipitation x juniper site index	.657
X_{14}	Precipitation x stoniness of surface	.072

By scanning the output data in reverse order, it was possible to choose the particular regression model with the fewest number of independent variables consistent with some desired r^2 value. Or, to put it another way, all the variables which seemed to make the least contribution to the estimating equation could be dropped out. Residual variables which remained in the step-wise program the longest are displayed for each control practice and appropriate province in Table 7.d.2 (a, b, and c).

Table 7.d.2b. Partial correlation of residual variables with seeded grass production in the La Sal province (broadcast and chain)

Residual variables		R
X_{26}	Pinyon site class x grass production prior to treatment	.737
X_{15}	Precipitation x pinyon site index	-.052
X_{22}	Grass production prior to treatment	-.062
X_{16}	Precipitation x juniper site index	.449
X_{21}	Pinyon site index x juniper site index	-.047
X_8	Stoniness of surface	.394
X_{17}	Depth A horizon x stoniness surface	-.052
X_{10}	Juniper site index	.059

Table 7.d.2c. Partial correlation of residual variables with native grass production in the Coronado province (chain or cable only)

Residual variables		R
X_{26}	Pinyon site index x grass production prior to treatment	.651
X_{13}	Precipitation x stoniness surface	.506
X_{24}	Precipitation x grass production prior to treatment	.624
X_6	Latitude	-.367
X_7	Stoniness A horizon	.503
X_8	Stoniness of surface	.423
X_{14}	Precipitation x stoniness of surface	.421

Table 7.d.3a. Residual variables and regression coefficients for selected control practices - Escalante-Sevier (chain, windrow, and drill)

Variable		Regression coefficient
X_3	Depth A and B horizon	-1094.4752**
X_{21}	Pinyon sites ht. x juniper site index	- 28.2317**
X_5	Development of B horizon	+2260.4283**
X_{19}	Development of B x pinyon site index	- 112.5741**
X_{15}	Precipitation x pinyon site index	+ 28.8118**
X_8	Stoniness surface	- 300.2593*
X_9	Pinyon site index	+ 553.6036**
X_{16}	Precipitation x juniper site index	+ 41.8800**
X_{14}	Precipitation x stoniness surface	+ 21.3885*

Table 7.d.3b. Residual variables and regression coefficients for selected control practices - La Sal (broadcast and chain)

Variable		Regression coefficient
X_{26}	Pinyon site index x grass production prior	+ 1.2806**
X_{15}	Precipitation x pinyon site index	+12.1509**
X_{22}	Grass production prior	-32.5088**
X_{16}	Precipitation x juniper site index	- 6.7530^{NS}
X_{21}	Pinyon site index x juniper site index	-12.1740**
X_8	Stoniness surface	-63.4908**
X_{17}	Depth x stoniness surface	+ 7.5444**
X_{10}	Juniper site index	+421.6531*

Table 7.d.3c. Residual variables and regression coefficients for selected control practices - Coronado (chain and cabled)

Variable		Regression coefficient
X_{26}	Pinyon site index x grass-production prior	+ 0.1299**
X_{13}	Precipitation x stoniness A	- 2.4041**
X_{24}	Precipitation x grass production prior	- 0.1167**
X_6	Latitude	- 6.8787**
X_7	Stoniness A horizon	+41.7481**
X_8	Stoniness surface	-72.5863**
X_{14}	Precipitation x stoniness surface	+ 4.7158**

**Significant at 0.05 level.
*Significant at 0.01 level.

Table 7.d.4. Estimating equations for forage response

		r	r^2
Escalante-Sevier Chain, windrow, drill	$\hat{Y}_1 = 2978.70 - 1094.48 X_3 - 28.23 X_{21}$	.861	.742
	$+ 2260.43 X_5 - 112.57 X_{19} + 28.81 X_{15}$		
	$- 300.26 X_8 + 553.60 X_9 + 41.88 X_{16}$		
	$+ 21.39 X_{14}$		
La Sal Broadcast and chain	$\hat{Y}_2 = 3949.81 + 1.28 X_{26} + 12.15 X_{15}$	.885	.783
	$- 32.51 X_{22} - 6.75 X_{16} - 12.17 X_{21}$		
	$- 63.49 X_8 + 7.54 X_{17} + 421.65 X_{10}$		
Coronado Chain only	$\hat{Y}_3 = 240.86 + 0.13 X_{26} - 2.40 X_{13}$	.904	.816
	$- 0.19 X_{24} - 6.88 X_6 + 41.75 X_7$		
	$- 72.59 X_8 + 4.72 X_{14}$		

Y_1 and Y_2 are seeded grass production and Y_3 is native grass production.

Results-- With all original variables included [Table 7.d.1], the coefficient of determination for each model was greater than 0.90. Models containing only the residual variables have r^2's of approximately 0.74, 0.78, and 0.82 for each practice, respectively. Table 7.d.3 (a, b, and c) contains these coefficients along with the results of F tests on β values. Except for one instance, all of these regression coefficients were significant at the 0.01 or 0.05 levels. Estimating equations are in Table 7.d.4.

In some instances the algebraic signs of the regression coefficients are the reverse of what might otherwise be expected. These signs may be compared with those of the simple correlation coefficients shown in Table 7.d.2 (a, b, and c), which, by and large, have the signs that would be thought normal. The "reversed" signs in the estimating equations simply prove that interaction between the X_i's in question and at least one other variable is so great that the expected sign is "swamped out."

Conclusion-- These estimating equations are based on collection of only one year's data. They should be used with caution. As an experiment, the site factors associated with a number of 1964 grass production observations were introduced into the appropriate estimating equations. The 1964 data were taken from control projects also visited in 1965. The expected production, $\hat{Y}$, was compared with actual production in a Chi square test (even though the sample sizes were small: 3 to 6 degrees of freedom). An example of the results is shown in Table 7.d.5. Only Escalante-Sevier data need be shown.

The null hypothesis is that there is no significant difference between actual and expected production within the same province when utilizing the same tree control method. But since any χ^2 above 16.0 (with 3 degrees of freedom) means that there is virtually a 100 percent chance that the sample of actual observations did not come from the expected population, the hypothesis would be rejected. On purely statistical grounds it would be rejected with respect to the results obtained using 1964 La Sal and Coronado data as well.

Part of the difficulty inherent in the application of the developed estimating equations is tied to site factor interactions. But more important is

Table 7.d.5. Chi-square test of Escalante-Sevier estimating equation employing 1964 data

Study number	Grass production (lbs acre) 1 Expected	 2 Actual	$\frac{(2-1)^2}{1}$
176	577	527	4.33
171	1323	341	728.9
173	232	118	56.0
182	770	811	2.28
			$\chi^2 = 791.4$

that cross-sectional data do not capture the great annual fluctuations in forage prouction. What is needed are time series data from a variety of projects. Then the estimating equations could be linked to an average of several year's production figures.

Nonetheless, it is possible to learn a good deal about conversion alternatives from an analysis of the quantity of cross-sectional data accumulated during the course of the present study. Section 8 of this report has been developed to provide recommendations concerning the role of individual site factors for enhancing success in seeding and conversion projects. These recommendations should prove especially useful in the selection of eradication and seeding sites.

7.e. How Tree Removal Affects the Amount of Usable Acreage -- H. E. Isaacson

All three of the basic tree removal treatments considered take portions of the conversion project completely of production because of downed tree material. Treatments that do not involve piling or windrowing downed material also restrict utilization of forage by livestock because of coverage by dead tree crowns. This is not a permanent loss; the tree crown deterioration process allows most of this forage to become available in about 5 years where there is pressure from cattle, but the time process may be extended with light use or with smaller livestock.

On seeding projects where downed trees were windrowed, a rough measurement of several portions of these projects was made to determine the amount of area taken up by piled debris. Windrowing causes 3-10 percent of the area to be nonproductive. If these piles are burned, the bare strips will probably fill in with some form of vegetation; however, it will take considerable time for grass to be dominant.

A higher percentage of nonproductive or unavailable area is generally associated with projects that are not windrowed. An estimate was made in each of the 9.6 square foot grass production plots of the percentage of the area in the plot that heavy debris made unproductive or unavailable to large grazing animals. These estimates were averaged for each project and it was found that the percent of unusable acreage ranges from approximately 5 to 35 percent.

In order to provide a guide for unusability predictions where no windrowing is planned, the tree canopy percentages of the adjacent woodland stands were plotted against unusability on various projects. For the first five years following conversion, unusable acreage will be at the rate of 9.3•(% crown canopy per acre) and thereafter at the rate of 0.7•(% crown canopy per acre).

Table 7.d.6. Listing of regression variables used singly or in combination

X_1 Precipitation in inches

X_2 Depth of A horizon in inches

X_3 Depth of the A and B horizon in inches

X_4 Texture of the A horizon, valued as follows:

1. Loamy-sand to sand
2. Silty-clay to clay
3. Sandy-loam
4. Sandy-clay, silty-clay loam and clay-loam
5. Sandy-clay, silty-loam, silt and loam

X_5 Development of the B horizon, valued as follows:

1. Well developed B_2 layer
2. Well defined B_1 or B_3 layer
3. Poorly developed B_1 or B_3 layer
4. Possesses some B horizon properties (A_3 or A_c horizon)
5. Little or no evidence of B horizon

X_6 Latitude - The numbering system initiated at the extreme south end of the province and increased one for each 10' in latitude.

Example: 37° 00' = 1; 73" 10' = 2, etc.

X_7 Stoniness in the A horizon in percent

X_8 Stoniness on the surface in percent area covered

X_9 Pinyon site index - This is the height of trees with a 10 inch stem diameter measured one foot from the ground and is given in feet.

X_{10} Juniper site index - This is the height of trees with a 10 inch stem diameter measured one foot from the ground and is given in inches and feet.

X_{22} This is an estimate of air-dry grass production per acre in pounds per acre on the project area prior to treatment. This was taken from the untreated area adjacent to projects

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Water Supply Forecast Unit and Office of State Climatologist, U. S. Weather Bureau, Salt Lake City, Utah. Isohyetal map of Normal Annual Precipitation, 1931-1960 for the state of Arizona.

8. CONVERSION DECISION: RECOMMENDATIONS

Except for special cases, the best current use of pinyon-juniper lands in the Great Basin and Colorado Plateau is to provide forage for grazing animals. Rehabilitation programs will be based upon potential of an individual site to respond to either livestock control as a means of improving range health or tree eradication to increase forage production. A decision to manipulate the cover type must be based on sound ecological principles. This section provides guidance for making alternative management decisions. If eradication of a woodland stand is contemplated, consideration should be given to the site qualifications necessary to promote success and the technique combinations applicable to the chosen area.

8.a. General Considerations When Choosing Conversion Sites -- E. Eberhard, R. J. Rivers, and H. E. Isaacson

A general requirement is to restrict choices to areas of uniform site conditions with slopes less than 15 percent.

On individual sites it is necessary to determine average percent tree canopy cover per acre and the pounds per acre yield of understory grass vegetation. This should be accomplished by methods similar to those used in collecting data for this study. Potential forage production is estimated from the proper canopy/grass production curve in Figures 7.a.1, 7.a.2, and 7.a.3. Providing there is a fair seed stock of valuable forage plants left, a prediction of the potential forage increases that are possible through management practice can then be made. If sufficient potential exists, the benefits from increased production can be balanced against grazing deferrment "losses" that must be incurred during the 5-8 year rehabilitation period.

If existing range conditions are deteriorated or the potential is low due to heavy canopy, tree eradication with some form of seeding practice may be the only way to improve forage production. In the process, watershed benefits may be quite worthwhile. In portions of the pinyon-juniper woodlands, understory plants are almost non-existent. Topsoil between individual tree litter cover is susceptible to erosion. Tree roots do not have the same restraining effect on soil loss as grass. The chaining process alone, leaving a mass of protective litter, improves watershed conditions on sites of less than 15 percent slope.

If drilling is not contemplated, sites with a high percentage of pinyon should be given first consideration, not only because precipitation levels might be better, but also because the re-growth characteristics of pinyon should permit greater conversion longevity. While the general rule is to predict kill on the basis of number of stems per acre ≥ 7", in no case should chaining or cabling (without slash treatment) be attempted where the tree stand contains 250-300 stems per acre in the 3" and lower diameter classes; longevity of such conversions might only be 20 to 30 years. Longevity can be estimated in a rough fashion by referring to Figures 6.c.4 through 6.c.7 (based on residual tree growth to reach specific percentages of canopy closure).

If possible, the slash on non-drilled conversions should be burned. This will tend to increase kill percentage and lower the amount of heavy slash cover.

If these first steps substantiate the feasibility of eradicating the tree stand, the following guide should be considered for greatest possibility of success.

8.b. Treatment Choice by Province -- H. E. Isaacson

Escalante-Sevier Province-- A. Chain or cable only - Visits were made to only 5 projects which had received this treatment. Four of the five showed a significant increase in production (Table 7.c.1), yet total grass production after treatment was low on all but two. Prior to treatment, these two were open tree stands with good grass cover. Bluebunch wheatgrass and Indian ricegrass made up 40 percent of the understory composition. The recommendation should be to remove tree competition where good productive species already exist.

B. Broadcast introduced grass seed and chain or cable - This treatment showed erratic results in this province. Only 2 of 10 projects (Table 7.c.2) show fairly high production of seeded grass. On a homogeneous site, this practice was applied over a period of several years and results differed greatly. Apparently a good year (precipitation wise) is necessary for seeded grass establishment. A higher degree of success occurs on the windward side (east side) of mountain ranges in a precipitation zone 14 inches or higher. This treatment would only be recommended on extremely favorable sites.

C. Chain, windrow slash and drill introduced grass seed - This technique was used extensively in this province. It is the only treatment consistently successful in the pinyon-juniper type. Latitude may have an affect on production as will site quality. Treatment is highly recommended on qualified sites. Care should be taken in choosing sites because the treatment removes all vegetation prior to seeding. Important browse ranges should not be so intensively treated.

La Sal Province-- A. Chain or cable only - This practice is somewhat more successful than in the Escalante-Sevier province. It is recommended only where a good stand of native bunch grass will provide a source of seed. The following species, Indian ricegrass, mutton grass, bluebunch wheatgrass, or beardless wheatgrass, should make up at least 40 percent of the understory composition and should be uniformly distributed.

B. Broadcast introduced grass seed and chain or cable - This is the most common practice in the province and is consistently successful on high quality sites. While more forage is produced by clearing and drilling, the broadcasting technique is cheaper (Table 7.c.10 shows the significant difference in grass production between the treatments on the same sites). It is highly recommended on suitable sites.

C. Chain, windrow slash, and drill introduced grass seed - Most of the observations of this technique were not eradication projects but involved clearings along power lines and roads. It proved highly successful and is recommended if cost is not a limiting factor.

Coronado Province-- A. Chain or cable only - With the existing good cover of grass (blue grama, side oatsgrama, galletta grass, and mutton grass) generally found in pinyon-juniper woodlands, this practice has been used extensively to release the native species. Table 7.c.7 shows highly significant increases in the majority of projects but less than half show significant increases in grass basal area over those of the comparison plots. Thus, much of the increase in production comes from gains in vigor of the existing grass stand. This treatment is recommended for the Coronado province because of the lack of success in establishing introduced grass species. Production increases are not as dramatic as successful seeding projects in the other provinces, but production gains complement a practice otherwise necessary to halt invasion of short grass ranges.

B. Broadcast introduced grass seed and chain or cable - Few of these projects show much promise; successful ones were in precipitation zones of 15-18 inches. The practice of burning the area prior to broadcast seeding with crested wheatgrass proved successful on the Haulipi Indian reservation. Recommendation would be to seed crested wheatgrass or Siberian wheatgrass at sites where the known winter and spring precipitation is sufficient. These conditions are rarely met in the pinyon-juniper zone of this province. No lovegrass seedings visited in the province were considered successful.

C. Chain, windrow slash, and drill introduced grass seed - This practice is not common but several places along power lines south of Farmington, New Mexico, provided comparisons of broadcasting versus drilling grass seed. The treatment would be recommended on the same sites as for the broadcast technique.

8.c. Precipitation Recommendations by Province -- H. E. Isaacson

A good estimate of average annual precipitation at a proposed conversion location is available from isohyetal maps of Utah and Arizona which have been published by the Water Supply Forecast Unit, U. S. Weather Bureau, Salt Lake City, Utah. A similar group of maps covering western Colorado and northwestern New Mexico are attached to the Upper Colorado River Basin Report, U.S.G.S. Professional Paper 442 [Iorn and Hembre, 1964]. Estimates for Nevada will have to be made using the best information available.

Tables 8.c.1, 8.c.2, and 8.c.3 show how certain species common to the pinyon-juniper type are related to precipitation zones in each province. This knowledge will be of assistance when making precipitation estimates in the field.

Of primary importance when seeding grass throughout the study area is seasonal distribution of precipitation. It is probably the main environmental factor involved in the success of failure of establishing stands of grass. The introduced grass species measured in the study area (mainly crested wheatgrass and intermediate wheatgrass) require early spring moisture to become established.

Province No. 1 (Escalante-Sevier)-- The recommended seeding practice (Table 8.e.1) in this province is drilling. This technique proves successful for crested wheatgrass when the average annual precipitation is 12 inches or more. Although intermediate wheatgrass has been successful at sites receiving as little as 12 inches precipitation, the recommended level is 14 to 16 inches.

If a broadcast crested wheat project is attempted, it would be planned for a site that receives 14 or more inches of precipitation.

Province No. 2 (La Sal Province)-- If the grass seed is to be drilled following tree removal, the precipitation requirement is 12 inches for crested wheatgrass and 14 inches for intermediate wheatgrass. Projects that are broadcast sown

Table 8.c.1. Common species of the Escalante-Sevier province as they are related to average annual precipitation

Species Common name	Botanical name	Inches, Average Annual Rainfall 9	10	11	12	13	14	15	16	17	18
Big sagebrush	Artemisia tridentata	X	---	---	---	---	---	---	---	---	---
Low sagebrush	Artemisia spp.	X	---	---	---	---	---	---	---	---	---
Bitter brush	Purshia tridentata	X	---	---	---	---	---	---	---	---	---
Squirrel tail	Sitanian hystrix	X	---	---	---	---	---	---	---	---	---
Sandburg bluegrass	Poa secunda	X	---	---	---	---	---	---	---	---	---
Indian ricegrass	Oryzopsis hymenoides	X	---	---	---	---	---	---	---	---	---
Nevada bluegrass	Poa nevadansis			X	---	---	---	---	---	---	---
Bluebunch wheatgrass	Agropyron spicatum			X	---	---	---	---	---	---	---
Balsam root	Balsamorhiza sagitata				X	---	---	---	---	---	---
Low larkspur	Delphinium spp.				X	---	---	---	---	---	---
Tall phlox	Phlox spp.				X	---	---	---	---	---	---
Service berry	Amelanchier spp.						X	---	---	---	---
Snow berry	Symphoricarpos spp.						X	---	---	---	---
Idaho fescue	Festuca idahoensis						X	---	---	---	---
Mountain mahogany	Cercocarpus ledifolius							X	---	---	---

Table 8.c.2. Common species of the La Sal province as they are related to average annual precipitation

Species Common name	Botanical name	Index, Average Annual Precipitation 9	10	11	12	13	14	15	16	17	18	19	20
Big sagebrush	Artemisia tridentata	X	---	---	---	---	---	---	---	---	---	---	---
Low sagebrush	Artemisia spp.	X	---	---	---	---	---	---	---	---	---	---	---
Squirrel tail	Sitanian hystrix	X	---	---	---	---	---	---	---	---	---	---	---
Indian ricegrass	Oryzopsis hymenoides	X	---	---	---	---	---	---	---	---	---	---	---
Blue grama	Bouteloua gracilis	X	---	---	---	---	---	---	---	---	---	---	---
Mutton grass	Poa fendlariana	X	---	---	---	---	---	---	---	---	---	---	---
Bitter brush	Purshia tridentata				X	---	---	---	---	---	---	---	---
Bluebunch wheatgrass	Agropyron spicatum				X	---	---	---	---	---	---	---	---
Beardless wheatgrass	Agropyron inerme				X	---	---	---	---	---	---	---	---
Shrubby penstemon	Penstemon spp.				X	---	---	---	---	---	---	---	---
Alder-leaf mahogany	Cercocarpus montanus				X	---	---	---	---	---	---	---	---
Snowberry	Symphoricarpos spp.						X	---	---	---	---	---	---
Serviceberry	Amelanchier spp.						X	---	---	---	---	---	---
Goldenrod	Solidago spp.						X	---	---	---	---	---	---
June grass	Koeleria cristata						X	---	---	---	---	---	---
Lupine	Lupinus spp.						X	---	---	---	---	---	---
Tall phlox	Phlox spp.						X	---	---	---	---	---	---
Hairy golden aster	Chrysopsis villosa						X	---	---	---	---	---	---
Arizona fescue	Festuca arizonica						X	---	---	---	---	---	---
Gambel oak	Quercus gambelii						X	---	---	---	---	---	---
Balsam root	Balsamorhiza sagitata							X	---	---	---	---	---
Squaw apple	Peraphyllum ramosissimum								X	---	---	---	---
Vetch	Vicia spp.										X	---	---
Ponderosa pine	Pinus ponderosa										X	---	---

Table 8.c.3. Common species of the Coronado province as they are related to average annual precipitation

Species Common name	Botanical name	Inches, average annual precipitation											
		9	10	11	12	13	14	15	16	17	18	19	20
Big sagebrush	Artemisia tridentata	X----	----	----	----	----	----	----	----	----	----	----	----
Blue grama	Bouteloua gracilis	X----	----	----	----	----	----	----	----	----	----	----	----
Side oats grama	Bouteloua curtipendula	X----	----	----	----	----	----	----	----	----	----	----	----
Squirrel tail	Sitanian hystrix	X----	----	----	----	----	----	----	----	----	----	----	----
Indian rice grass	Oryzopsis hymenoides	X----	----	----	----	----	----	----	----	----	----	----	----
Algerita	Berberis fremontii	X----	----	----	----	----	----	----	----	----	----	----	----
Three awned grass	Aristida spp.	X----	----	----	----	----	----	----	----	----	----	----	----
Galleta grass	Hilaria jamesii			X----	----	----	----	----	----	----	----	----	----
Shrubby penstemon	Penstemon spp.				X----	----	----	----	----	----	----	----	----
Bitter brush	Purshia tridentata				X----	----	----	----	----	----	----	----	----
Western wheatgrass	Agropyron smithii					X----	----	----	----	----	----	----	----
June grass	Koeleria cristata					X----	----	----	----	----	----	----	----
Dryland carex	Carex spp.						X----	----	----	----	----	----	----
Kentucky bluegrass	Poa pratensis						X----	----	----	----	----	----	----
Alder-leaf mahogany	Cercocarpus montanus						X----	----	----	----	----	----	----
Snowberry	Symphoricarpos spp.						X----	----	----	----	----	----	----
Service berry	Amelanchier spp.						X----	----	----	----	----	----	----
Gambel oak	Quercus gambelii						X----	----	----	----	----	----	----
Arizona fescue	Festuca arizonica							X----	----	----	----	----	----
Pine dropseed	Blepharoneuron tricholepsis							X----	----	----	----	----	----
Arctostaphylus petula	Arctostaphylus petula										X----	----	----
Ponderosa pine	Pinus ponderosa										X----	----	----

generally require 14 inches or more. Intermediate wheatgrass can also be used in the seed mixture on the more favorable sites.

Province No. 3 (Coronado)-- Any introduction of created wheatgrass appears to require 15 inches of precipitation. The sites must receive fairly heavy winter and spring moisture. The annual growth period for this province is in the spring, which is unfavorable for growing crested wheatgrass.

8.d. Soil Factor Recommendations -- E. J. Eberhard

Where seeding is contemplated, all the following factors must be considered.

Total depth-- Sixteen inches is recommended, but success has been observed with 12-16 inches (texture was medium to fairly heavy) where the soil has a definite B horizon to prevent loss of moisture into the sub-soil.

Depth of A layer-- Recommend 7-12 inches but in higher precipitation zones (16 inches or more) 5 inches may be sufficient with a well developed B horizon.

Texture of the A horizon-- Good seeded grass production has been achieved on a variety of soil textures. Sandy loam to clay loam spans the texture classes where seedings should be attempted. Outside these textural extremes a decision to seed is questionable. On lighter textured soils (sandy loam) a definite B horizon is necessary for grass establishment and good production.

Development of B horizon-- Recommend at least a weakly developed B horizon. A strong B horizon holds the soil moisture in the root zone for longer periods of time during seasonal growth.

Tree site index-- The height of both pinyon and juniper trees at a specific trunk diameter at the one foot height should be a good expression of site productivity for seeded grass. But the study did not confirm this relationship.

Pinyon trees taller than 24 feet with 10 inch diameters measured one foot from the ground were generally associated with high grass production. Juniper should be over 20 feet high at 10 inches to make the same assumption.

8.e. Tabulated Recommendations -- H. E. Isaacson

The information in Tables 8.e.1 and 8.e.2 is meant to guide choice of site for growing seeded grass in the woodland type (no seeding recommendations are given for Coronado province). Few sites will live up to all the recommended site factors. If some of the factors fall a little short or into the "possible" column, success will probably still be achieved. There are no sharp boundaries where site factors will always predict success or certain failure. Factors interact and some factor limitations will be offset by other factor potentials. Tables 8.e.3, 8.e.4, and 8.e.5 illustrate how "within treatment" seeded grass production varied with site factors.

Table 8.e.1. Recommendations for seeding pinyon-juniper stands in the Escalante-Sevier Province

Ecological factors	Treatments				
	Chain or cable only[b]	Broadcast grass seed and chain or cable[c]		chain or cable, windrow trash and drill seed	
		Possible	Recommended	Possible[a]	Recommended
Precipitation	Where good Stand of native Grass in open Stand of trees		14 + inches	12-14 inches	12-14 inches
Total soil depth			16 + inches	12-16 inches	16 + inches
Depth A horizon			7 + inches	5-7 inches	7 + inches
Texture A horizon			Sandy loam to clay loam	Sandy loam to clay loam	Sandy loam to clay loam
Development of B horizon			Well developed	Weakly developed	Well developed
Species to seed			Crested wheatgrass	Crested wheatgrass	Crested wheatgrass to intermediate wheatgrass
Comments:			Best results on windward side of mountains. May be successful in cycle of good year only.	It appears that in the southern latitudes, seedings do not produce as much volume per acre. Possibly best sites only should be converted.	

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[a] If some of these conditions are found on sites but the preponderence of site factors fall into the recommended group, the chance for seeding success is still very good.

[b] Not recommended where soil texture is lighter than sandy loam or heavier than clay loam.

[c] Native grass production on the site prior to treatment has a definite inverse effect on resulting seeded grass production; however, it has a lesser influence on total grass production, both seeded and native after treatment.

Table 8.e.2. Recommendations for seeding pinyon-juniper stands in the La Sal Province

Ecological Factor	Treatment				
	Chain or cable only[b]	Broadcast grass seed and chain or cable[c]		Chain or cable, windrow trash and drill seed	
		Possible[a]	Recommended	Possible[a]	Recommended
Precipitation	Where good Stand of bunchgrass Species Uniformly Distributed	12-14 inches	14 + inches	12-14 inches	14 + inches
Total soil depth		12-16 inches	16 + inches	12-16 inches	16 + inches
Depth A horizon		5-7 inches	7 + inches	5-7 inches	7 + inches
Texture A horizon		Sandy loam to clay loam	Sandy loam to clay loam	Sandy loam to clay loam	Sandy loam to clay loam
Development of B horizon		Weakly developed	Well developed	Weakly developed	Well developed
Species to seed		Crested wheatgrass	Crested wheatgrass	Crested wheatgrass	Crested, intermediate, and pubscent

Comments:

[a] If some of the factors fall into this category but the majority are in the recommended category, success will probably be achieved.

[b] Not recommended where soil texture is lighter than sandy loam or heavier than clay loam.

[c] Native grass production on the site prior to treatment has a definite inhibiting effect on resulting seeded grass production; however, it has a lesser influence on total grass production (both seeded and native) after treatment.

Table 8.e.3. Examples of low, fair, and high productive grass stands in the Escalante-Sevier province following treatment by windrowing slash and drilling crested wheatgrass seed after chaining

Ecological factors	Degree of success[a]		
	Low production 492 lbs/acre	Fair production 916 lbs./acre	High production 1545 lbs./acre
Slope	4%	10%	4%
Tree canopy prior to treatment	25%	28%	14%
Precipitation	11 inches	12 inches	16 inches
Total depth soil	40 inches	60 inches	40 inches
Depth A lyaer	12 inches	6 inches	13 inches
Texture A layer	loam	clay loam	sandy loam
Development B layer	poor development	poor development	well developed
Stoniness A horizon	10%	40%	5%
Pinyon ht. at 10" diameter	15 feet	23 feet	22 feet
Juniper ht. at 10" diameter	15 feet	13 feet	18 feet
Comments:	Low precipitation and poor B layer, probably responsible for poor production. Note: short trees.	Poor B layer and stoniness effect production. Juniper trees short at this site.	High precipitation and good B layer make excellent site. Pinyon and Juniper trees are tall.

[a] Air-dry production crested wheatgrass in lbs./acre.

Table 8.e.4. Examples of failure, fair success, and successful grass stand in the La Sal province for the treatment of broadcasting crested wheatgrass seed prior to chaining trees

Ecological factors	Degree of success[a]		
	Failure 0 lb./acre	Fair stand 506 lb./acre	Successful stand 1027 lbs/acre
Slope	3%	7%	0
Tree canopy prior to treatment	16%	19%	32%
Precipitation	10 inches	14 inches	14 inches
Total depth soil	50 inches	22 inches	36 inches
Depth A layer	5 inches	7 inches	10 inches
Texture A layer	Almost sand	Almost sand	Medium texture
Development B layer	None	None	Well developed
Stoniness A horizon	0	5%	0
Pinyon ht. at 10" diameter	18 feet	20 feet	24 feet
Juniper ht. at 10" diameter	15 feet	17 feet	25 feet
Comments:	Soil too sandy, no B horizon to hold moisture in root zone, precipitation too light	Soil too sandy, no B horizon, precipitation only reason for fair stand of seeded grass	Excellent site

[a] Air-dry production crested wheatgrass in lbs./acre.

Table 8.e.5. Examples at low, fair, and high production grass stands in the Coronado province following treatment by broadcasting crested wheatgrass prior to chaining or cabling trees

Ecological factors	Degree of success[a]		
	Low production 0 lbs./acre	Fair production 300 lbs./acre	High production 1200 lbs./acre
Slope	0	8%	4%
Tree canopy prior to treatment	17%	26%	36%
Precipitation	14 inches	16 inches	15 inches
Total depth soil	55 inches	24 inches	30 inches
Depth A horizon	10 inches	6 inches	6 inches
Texture A horizon	Loamy sand	Silt	Sandy loam
Development B layer	Weak development	Poor development	Poor development
Stoniness of A horizon	0	5%	5%
Pinyon ht. at 10" diameter	22 feet	20 feet	31 feet
Juniper ht. at 10" diameter	16 feet	17 feet	22 feet
Comments:	Only weak factors are B horizon and texture (too sandy).	Only weak factor is B horizon.	Only indication that this site is better than other two is tree height.

[a] Air-dry production crested wheatgrass in lbs./acre.

9. VOLUME-TABLES AND TREE PRODUCTS

R. J. Rivers

That pinyon-juniper woodlands do have usable products is not disputed. The questions of how much and how valuable are debatable. Unfortunately, the answer to "how much" of any given product these lands have can only be answered with a woodland inventory. "How valuable" depends on market demands and trends in competition from substitutes. (See Vol. II of the report.)

Traditional products are pine nuts, fuel wood, mine props, fence posts, and Christmas trees. (In recent years some research has been done to determine the technological factors associated with charcoal and essential oil potential of these trees.) Since most of these products are marketed or utilized when within fairly narrow dimension ranges, management decisions must be based on some knowledge of growth rates. At present, data concerning the time it takes to produce a given woodland product are scarce. Chapman and Behre [1918] indicate that 150-170 years are required to produce a commercial grade mine prop, and approximately 73 years to produce a commercial (juniper) fence post.

Several volume tables for P-J woodlands are available. Probably the most thorough were prepared by the Soil Conservation Service [Howell, 1940]. Karl E. Moessner of the Forest Service has also prepared aerial volume tables for P-J stands [#69]. These volume tables are unique in that they facilitate aerial surveys of woodland stands for potential products such as fence posts.

9.a. Volume Tables

The volume tables presented in this discussion were developed from basic data presented in Table 8, page 36, and Table 10, page 38, of S.C.S. Regional Bulletin No. 71 [Howell, 1940]. Therefore, a brief discussion of the field sampling methods used in that study is in order.

The data were collected from 39 sites found in Arizona and New Mexico. The trees used in volume determination were cut to 4' lengths and down to a 2" diameter. Volume was calculated using Huber's formula [reference 6]. Cubic volume per tree for given diameter classes was next calculated.

Since only partial coverage of height and diameter classes was provided, the original number of volume observations has been increased by applying Schunacher's formula to the original height-diameter measurements. This analysis developed the constants necessary to predict volume for any chosen height-diameter relationship [reference 7].

$$\text{Log } V = \text{Log } a + b \text{ Log } D + c \log H ,$$

where

V = Volume in cubic feet

D = diameter

H = height,

Juniper:

$$\log Y = 04.6258 + 2.270 (\log D) + 0.359 (\log H) \quad .$$

Pinyon:

$$\log Y = -11.4321 + 0.2039 (\log D) + 4.0513 (\log H) \quad .$$

These formulas plus the appropriate conversion factors (to convert cubic feet to cords) were used in the construction of the Volume Tables presented in tables 9.a.1 to 9.a.4.

The Juniper Volume Tables were constructed from data listed as Juniperus monosperma, however, it is likely that the trees actually used would now be classified as Juniperus osteosperma. At the time the S.C.S. Bulletin was published, confusion existed over the form and range of these two species. The

Table 9.a.1. Pinyon volume tables (cubic feet)

Dia. @ 1'	Height 5	10	15	20	25	30	35	40	45
2	0.009	0.149	0.771						
4	0.011	0.182	0.943	3.025	7.472				
6	0.012	0.205	1.061	3.403	8.405	17.594	32.855		
8	0.013	0.223	1.153	3.700	9.138	19.127	35.717	61.352	98.870
10	0.014	0.238	1.230	3.948	9.750	20.408	38.108	65.459	105.488
12		0.251	1.297	4.162	10.280	21.517	40.180	69.018	111.224
14		0.262	1.357	4.353	10.750	22.502	42.020	72.178	116.316
16		0.272	1.410	4.525	11.175	23.392	43.681	75.031	120.915
18			1.460	4.682	11.564	24.206	45.201	77.642	125.122
20			1.505	4.828	11.924	24.958	46.606	80.054	129.010
22			1.547	4.963	12.258	25.658	47.913	82.301	132.630
24			1.587	5.091	12.572	26.315	49.140	84.407	136.024
26			1.624	5.210	12.868	26.934	50.295	86.392	139.223
28			1.659	5.324	13.148	27.520	51.389	88.271	142.251
30			1.693	5.431	13.414	28.077	52.429	90.058	145.130
32				5.534	13.667	28.608	53.421	91.761	147.876
34				5.632	13.910	29.116	54.370	93.391	150.502
36				5.727	14.143	29.603	55.280	94.954	153.021

Table 9.a.2. Pinyon volume tables (cords)

Dia. @ 1'	Height 5	10	15	20	25	30	35	40	45
2	0.000	0.002	0.011						
4	0.000	0.002	0.014	0.045	0.112				
6	0.000	0.003	0.015	0.051	0.126	0.264	0.493		
8	0.000	0.003	0.017	0.055	0.137	0.287	0.536	0.922	1.485
10	0.000	0.003	0.018	0.059	0.146	0.306	0.572	0.983	1.585
12		0.003	0.019	0.062	0.154	0.323	0.603	1.037	1.671
14		0.003	0.020	0.065	0.161	0.338	0.631	1.084	1.748
16		0.004	0.021	0.068	0.167	0.351	0.656	1.127	1.817
18			0.021	0.070	0.173	0.363	0.679	1.166	1.880
20			0.022	0.072	0.179	0.375	0.700	1.203	1.938
22			0.023	0.074	0.184	0.385	0.720	1.236	1.993
24			0.023	0.076	0.188	0.395	0.738	1.268	2.044
26			0.024	0.078	0.193	0.404	0.755	1.298	2.092
28			0.024	0.080	0.197	0.413	0.772	1.326	2.137
30			0.025	0.081	0.201	0.421	0.787	1.353	2.181
32				0.083	0.205	0.429	0.802	1.379	2.222
34				0.084	0.209	0.437	0.817	1.403	2.261
36				0.086	0.212	0.444	0.830	1.427	2.299

Table 9.a.3. Juniper volume tables (cubic feet)

Dia. @ 1'	Height-feet							
	5	10	15	20	25	30	35	40
2	0.084	0.108	0.125					
4	0.406	0.521	0.603	0.669	0.725			
6	1.021	1.310	1.515	1.680	1.821	1.944	2.055	
8	1.963	2.518	2.913	3.230	3.499	3.736	3.948	4.143
10	3.258	4.179	4.835	5.361	5.809	6.202	6.555	6.877
12		6.323	7.315	8.111	8.788	9.383	9.917	10.405
14		8.974	10.381	11.511	12.472	13.316	14.075	14.766
16		12.152	14.058	15.589	16.890	18.033	19.060	19.997
18		15.879	18.369	20.369	22.070	23.564	24.905	26.129
20		20.172	23.335	25.876	28.036	29.933	31.638	33.193
22			28.974	32.129	34.810	37.167	39.283	41.214
24			35.304	39.148	42.415	45.286	47.865	50.217
26			42.341	46.951	50.870	54.314	57.406	60.228
28			50.101	55.557	60.194	64.268	67.928	71.266
30			58.599	64.980	70.404	75.169	79.450	83.354
32				75.237	81.516	87.034	91.990	96.511
34				86.341	93.548	99.881	105.568	110.756
36				98.308	106.514	113.724	120.200	126.107

Table 9.a.4. Juniper volume tables (cords)

Dia. @ 1'	Height-feet							
	5	10	15	20	25	30	35	40
2	0.001	0.001	0.001					
4	0.006	0.008	0.009	0.010	0.011			
6	0.016	0.020	0.023	0.026	0.028	0.030	0.032	
8	0.031	0.039	0.046	0.051	0.055	0.059	0.062	0.065
10	0.051	0.066	0.076	0.084	0.091	0.097	0.103	0.108
12		0.099	0.115	0.128	0.138	0.148	0.156	0.164
14		0.141	0.164	0.181	0.197	0.210	0.222	0.233
16		0.191	0.222	0.246	0.266	0.284	0.301	0.315
18		0.250	0.290	0.321	0.348	0.377	0.393	0.412
20		0.318	0.368	0.408	0.442	0.472	0.499	0.524
22			0.457	0.507	0.549	0.587	0.620	0.651
24			0.557	0.618	0.670	0.715	0.756	0.793
26			0.668	0.741	0.803	0.858	0.906	0.951
28			0.791	0.877	0.950	1.015	1.073	1.125
30			0.925	1.026	1.112	1.187	1.255	1.316
32				1.188	1.287	1.374	1.453	1.524
34				1.364	1.477	1.577	1.667	1.749
36				1.553	1.682	1.796	1.898	1.992

tree dimensions reported in Bulletin 71 range up to 36" in diameter, which is possible for Juniper osteosperma, but not Juniperus monosperma. As a consequence, the present tables are presented simply as Juniper Volume Tables.

The present study suggests that form differences between Pinus monophylla and Pinus edulis are negligible. Tables 9.a.1 and 9.a.2 are considered valid for both species of pinyon pine.

Recommendations for future studies- It should be recognized that the basic data from which these volume tables were developed were collected by other researchers and only in New Mexico and Arizona. Therefore, from a technical viewpoint, these are regional in nature. If additional volume information were collected (using Huber's formula) from woodland observations in Colorado, Utah, and Nevada, it is possible that some variation from the data presented would exist. However, unless the economic value of P-J woodlands increases in the near future, there is little reason to strengthen these data by additional field samples.

9.b. Characteristics and Growth Trends of Pinus Monophylla Christmas Trees

Forty-five trees were collected at random from a storage yard at a Nursery in Logan, Utah, early in December, 1965. These trees were known to have been harvested from a particular area of B.L.M. administered land in eastern Nevada.

The various data collected from each tree included diameter outside the bark at 1', total height of the severed stem, and a disk from the bottom of the cut stem (approximately 1'). Height and diameter measurements were taken with a steel diameter tape, calibrated to the nearest 0.1 of an inch (for diameter) and the nearest 0.1 of a foot (for height).

Statistical analysis was confined to determination of means and variances for diameter, height, and age values of the 45 samples. A similar technique was used for a periodic increment analysis.

Analysis and discussion- The following data represent the mean and variance of the height, d.o.b., and total age at 1' of the 45 samples collected.

Height: 5.6' ± 0.86'
Diameter: 3.0" ± 0.45"
Age: 34.8 ± 7.1 yrs.

Since the operators of the nursery always do their own bidding and harvesting, it can be assumed the above data represent a close approximation to the pinyon tree dimensions most desired in current markets. These figures also indicate the average number of years required to reach a merchantable height class.

These age, height, and diameter relationships provide tentative guidelines for Christmas tree production on "potential sites." In this case, "potential sites" refers to areas suitably stocked with desired size classes and possessing the potential for producing adequate height and diameter increments. A. Andre, while studying the pinyon type in the White Mountains of California, noted that it was possible to grow a suitable tree (3.0" d.o.b.) in a period of 38 years on the better sites [1965]. This observation does not vary significantly from the results presented here.

Periodic growth increment- This analysis was designed to bring out any variations in growth patterns. Disc-inside-bark diameter increments were stratified by ten year age classes and summarized for the thirtieth and fortieth years.

Table 9.b.1 illustrates the percentage of total growth increment attributable to each ten-year interval for both the thirty and forty year-old diameter classes. The total increase in diameter growth between the 30th and 40th year diameter class is 63%. This growth pattern supports the conclusion of an earlier Soil Conservation Service study which indicated that maximum diameter increment for pinyon pine is during the 40th to 50th year age class [Howell, 1940].

Since variation about the mean for the 30 to 40 year increments is

Table 9.b.1. Periodic growth increment of 45 Pinus monophylla Christmas trees

Age class	Average diameter growth by 10 yrs. age classes		% of Total increment by 10 yr. age classes	
	1-30 years Dia. class	1-40 years Dia. class	1-30 year Age class	1-40 year Age class
1-10	0.36 ± .20 in.	0.36 ± .20 in.	19.2%	11.8%
11-20	0.62 ± .25 in.	0.62 ± .25 in.	33.3%	20.4%
21-30	0.89 ± .29 in.	0.89 ± .29 in.	47.5%	29.1%
31-40	-	1.18 ± .55 in.	-	38.7%
Totals	1.88 ± .69 in.	3.06 ± .107 in.	100.0%	100.0%

proportionally less than that of the 10 to 20 year increments, it may be inferred that the older the trees become, the greater the effect of site on diameter growth. It is possible that the diameter growth of the younger age classes is influenced more by stand position than by site characteristics.

These same relationships should be considered by technical personnel in deciding whether or not a given area would be of greater immediate value for Christmas tree production or alternative uses. On the better sites land managers may be able to increase diameter increment by as much as 63% by delaying harvest from the 30th to 40th year. Appropriate field measurements necessary to determine diameter increment would have to be performed on chosen sites before this practice is followed. Managers should not consider retaining Pinus monophylla sites for efficient Christmas tree production beyond the 50th year.

Recommendations for future studies- These data should be strengthened by additional sampling during the 1966 season. A similar study should be made on Pinus edulis.

9.c. Tree Products--Other than Christmas Trees

The volume tables presented in section 9.a, and the height-age relationships developed in section 6.c can be utilized to equate sites with wood products. The only additional statistical analysis necessary is one which will provide height-diameter relationships according to the same site break-down as the height/age curves.

Accordingly, a series of height/diameter curves has been developed. Diameter data were obtained from the same trees that supplied discs for age and height analysis. Disc diameters were averaged for given height classes. A total of 1070 pinyon and 1331 juniper trees were used for these measurements. These data were then stratified into 5 site combinations and analyzed in a logarithmic function:

$$\log Y = \log a + b (\log X),$$

where

Y = height

X = average diameter at 1'.

Table 9.c.1. Pinyon Sp. height/diameter regression analysis

Site class	Regression equation	R^2	Ht. class represented in analysis	Graph No.
11'-17'	$\log Y = \log 3.52 + 0.6469 (\log X)$	0.988	4'-28'	9.c.1
18'-23'	$\log Y = \log 3.54 + 0.7427 (\log X)$	0.993	4'-34'	9.c.1
24'-31'	$\log Y = \log 3.85 + 0.8104 (\log X)$	0.980	4'-45'	9.c.1
11'-20'	$\log Y = \log 3.79 + 0.6723 (\log X)$	0.957	4'-30'	10.a.3
21'-31'	$\log Y = \log 3.22 + 0.8566 (\log X)$	0.977	4'-45'	10.a.3

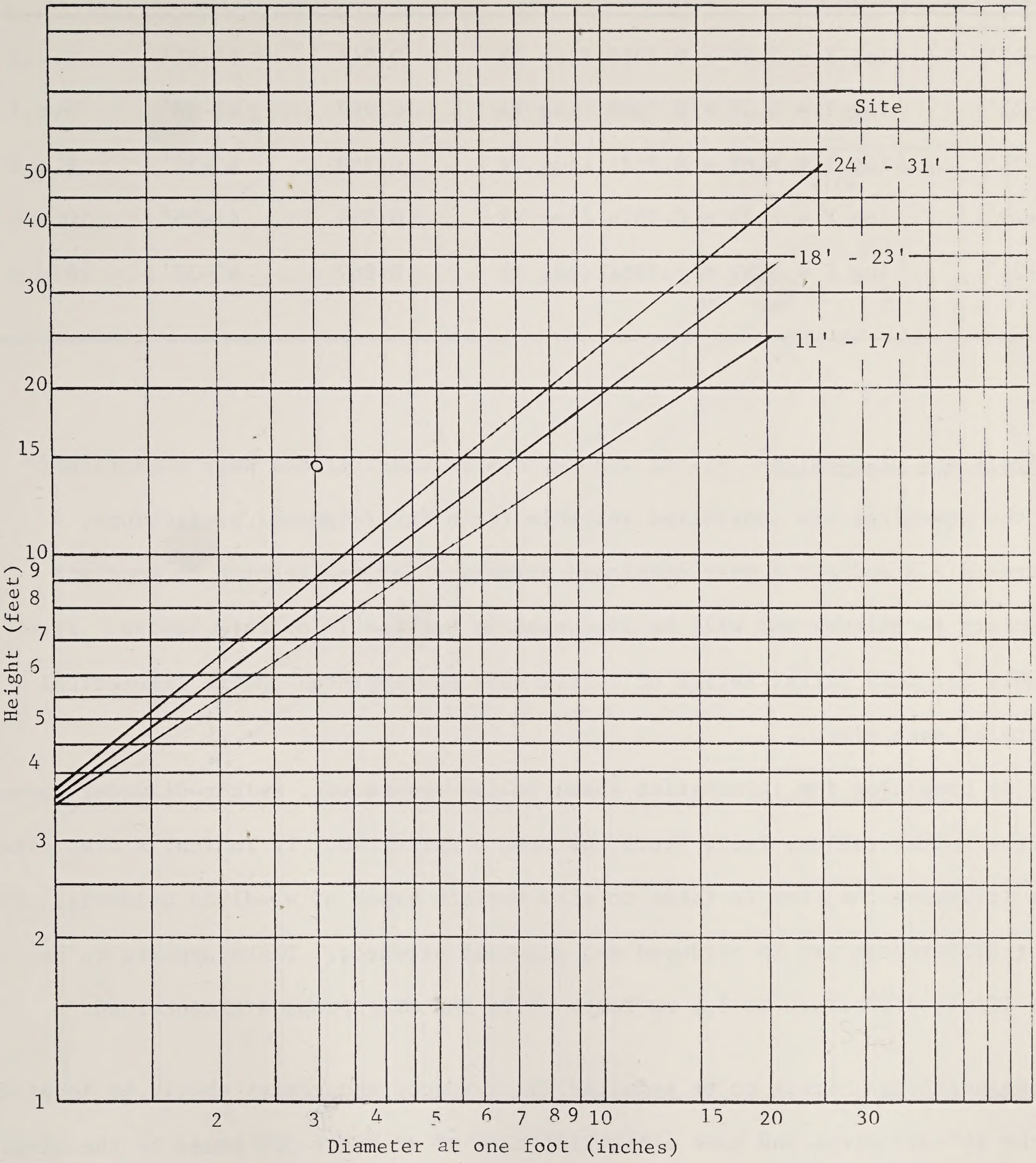

Figure 9.c.1. Pinyon Height-Diameter (all provinces)

Table 9.c.2. Juniper Sp. height/diameter regression analysis

Site class	Regression equation	R^2	Ht. class represented in analysis	Graph No.
11'-17'	log Y = 2.69 + 0.7069 (log X)	0.944	4'-21'	9.c.2
18'-23'	log Y = 3.31 + 0.7069 (log X)	0.967	4'-28'	9.c.2
24'-31'	log Y = 3.61 + 0.7521 (log X)	0.959	4'-32'	9.c.2
11'-20'	log Y = 2.79 + 0.7314 (log X)	0.939	4'-25'	10.a.4
21'-31'	log Y = 3.32 + 0.7581 (log X)	0.967	4'-32'	10.a.4

Analysis and discussion- All of the regression coefficients were significant and the equations are considered suitable for height/diameter predictions. Figures 10.a.3 and 10.a.4 were developed primarily for application in woodland inventory techniques and will be discussed in Section 10 of this report. Tree heights for this latter series of curves were extrapolated to the theoretical limits of each site.

By combining the information shown in the age-height, height-diameter curves and the volume tables, Table 9.c.3 has been constructed. It indicates that site does influence the time it takes to grow certain types of woodland products. The major differences are in cordwood and charcoal products. There appears to be very little difference as far as fence posts and mine props are concerned.

Recommendations- Areas to be selected for cordwood management should be located in the 24'-31' sites and have a stocking rate of at least 300 trees to the acre. Areas selected for fence post and mine prop management need not have as much emphasis placed on site. The prime criterion would be stocking rates. Future studies are not recommended unless the economic value of woodland tree products increases considerably.

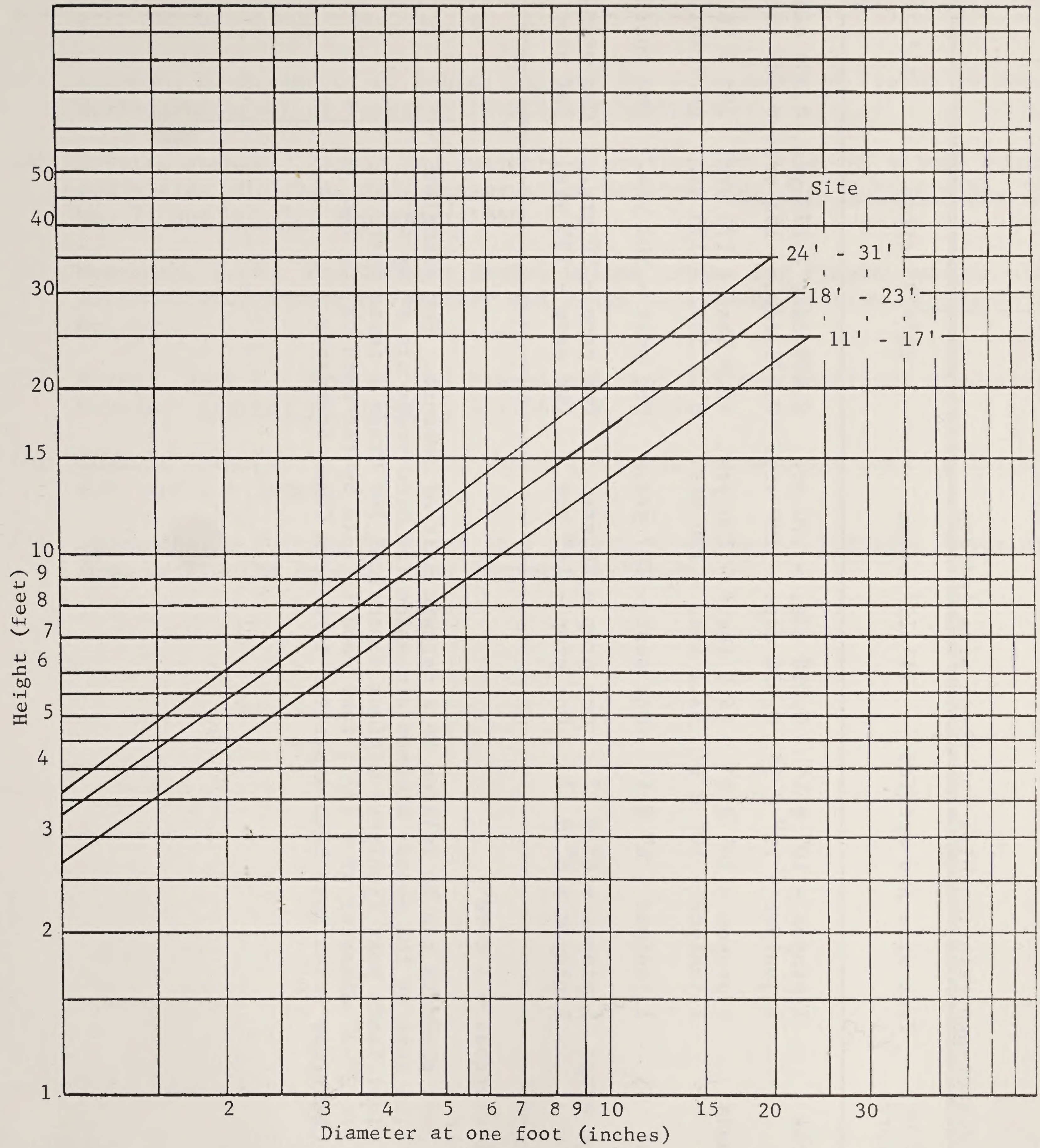

Figure 9.c. 2. Juniper Height-Diameter (all provinces)

Table 9.c.3. Product-age relationships for three site indices

Products	Unit of measure	Tree size and species	11'-17' sites	18'-23' sites	24'-31' sites
Fuelwood	Cords	1 pinyon - 10" @ 1'	0.018 cds. - 170 yrs.	0.059 cds. - 175 yrs.	0.306 cds. - 165 yrs.
		1 juniper - 10" @ 1'	0.076 cds. - 190 yrs.	0.075 cds. - 155 yrs.	0.084 cds. - 150 yrs.
Charcoal	Pounds	1 pinyon - 10" @ 1'	14.9 lbs.* - 170 yrs.	48.9 lbs. - 175 yrs.	253.9 lbs. - 165 yrs.
		1 juniper - 10" @ 1'	63.1 lbs. - 190 yrs.	63.1 lbs. - 155 yrs.	69.7 lbs. - 150 yrs.
Fence post	Post	1 juniper - 6" @ 1'	One post - 107 yrs.	One post - 102 yrs.	One post - 90 yrs.
Mine props	Mine props	1 pinyon - 6" @ 1'	One prop - 86 yrs.	One prop - 90 yrs.	One prop - 78 yrs.
		1 pinyon - 8" @ 1'	One prop - 145 yrs.	One prop - 135 yrs.	One prop - 125 yrs.

*830 lbs. of charcoal = 1 cord

Most products can be related to a certain unit of measure. For example: pine nuts by the pound; minimum dimension for mine props are 6' by 4" wide; fence post (juniper) minimum dimensions for Grade 3 fence post are 2"-3" diameter at 6 1/2'; fuel wood is sold by the cord or ton and Christmas trees have been separated into Form Class Standards.

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(5) Reveal, Jack L. Single leaf Pinyon and Utah Juniper woodlands of western Nevada. Journal of Forestry 42:276-278. 1944.

(6) Huber's formula: v = A 1/2L, where V = cubic volume, A = area at large end, and L = length.

(7) Schunacher's formula is found in : Spurr, Stephen H. Forestry Inventory. (New York: The Roland Press Company, 1952), p. 97.

10. INVENTORY TECHNIQUES

10.a. Suggested Woodland Inventory Techniques -- R. J. Rivers

The problem of how to develop a reasonable pinyon-juniper inventory has been of concern for a considerable period of time. The major difficulty has been how to apply standard "forest inventory" methods to a marginal vegetative type.

The purpose of this section is to suggest one solution to this problem. Three major steps are required:

1. Delineation of P-J type (on suitable maps);
2. Classification of P-J type into management units;
3. Inventory of P-J classified as "managable."

Type Mapping and Management Classification-- The first step is to map the area covered by pinyon-juniper woodlands. This can be done by using existing topographic maps and aerial photos. Once a preliminary map has been drawn showing the extent of the pinyon-juniper type, the next step is to classify these lands on the basis of management alternatives. In most cases management alternatives will depend on accessibility, slope and site potential of the area. The following management designations have been made as the basis of accessibility and slope. Site "potential" is evaluated in the inventory procedures.

The system outlined above can be refined depending on the administrative demands of the area; for example, Mu-1-R-3, could be interpreted to mean: Multiple use area, accessible, primary use is recreation development of existing cultural features (Indian ruins).

Table 10.a.1. Suggested classification of P-J lands by management alternations

Mapping unit	Map designation	Slope	Management alternations	Management limitations	Mapping unit (minimum)
Multiple use areas	Mu	0-15%	Forage 1. including conversion sites Recreation 1. Improved camp sites 2. Unimproved camp sites 3. Cultural sites 4. Scenic areas Woodland tree products 1. Cordwood 2. Fence posts 3. Christmas trees Wildlife Watersheds	1. Areas to be harvested for woodland tree products should be within 50-60 miles of a shipping center	1. 40 acres for recreational sites and Christmas tree areas. 2. All other areas should have a minimum unit of 160 acres.
1. accessible	Mu-1				
2. inaccessible*	Mu-2				
Limited management areas	Lm	16-30%	Forage Recreation 1. Cultural sites 2. Scenic sites	1. Woodland tree products should be within 50-60 miles of a shipping center.	1. 40 acres for recreation cultural sites and Christmas tree areas. 2. Minimum mapping unit for other sites is 320 acres
1. accessible	Lm-1				
2. inaccessible*	Lm-2				

REVIEW OF UTAH P-J REPORT

The report, "Management Alternatives for Pinyon-Juniper Woodlands - Part A," has been given critical review by several members of the Bureau's technical staffs. It is a very complex document containing several parts covering different aspects of the P-J type study. The dominant effort emphasized through the report relates to providing a site quality index and making it correlate with all other type evaluation factors. The degree of success here is uncertain and will be discussed more later in this review.

To lend some order to our comments, each identified portion of the report will be treated in sequence beginning with the preface. In this introductory portion, we note with a touch of apprehension the comment concerning possible inaccuracies in project identifications and tying them with office records. We must assume inconsequential errors in this respect. Also, the frontispiece referred to is a low quality map from which almost nothing can be definitely discerned. A larger scale with better drafting of study locations and other features would have served the intended function.

The table of contents would have been more enlightening if the names of the authors of each portion of the report had been appropriately inserted through it.

Section 1 augments the preface in describing circumstances and personalities involved in the initiation of the study. Time limits imposed by the

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Bureau are alluded to, but are not described as being such that only one year's collection of each type of data would be possible. This is perhaps the greatest deficiency of the study, prohibiting the evaluation and sampling of annual fluctuations in weather and production.

Section 2 is devoted to a description of field methodology for collecting forest, range, climatic, and soil and site data. Most of these procedures and most of the evaluation criteria measured seem entirely satisfactory. However, the method of selecting plot locations through the site tree designation procedures used appears to bias the data. Evaluations, therefore, would not be representative of typical site conditions. The tallest, most perfect tree found was designated the site tree. Such superior or elite trees hardly typify overall site productivity, and their growth characteristics differ markedly from that of the general tree stand.

Section 3 describes the ecological provinces used, some of the main characteristics of the P-J type, and restrictions imposed in sampling. The map showing the provinces is quite crude. It could be readily refined in several respects including province delineation and drafting quality. A disappointment was the discovery that only the flatter and more gently sloping sites (up to 15%) were studied. Obviously this was due to an assumption that steeper sites would not be treated. It apparently was true that steeper slopes had been infrequently treated up to the time of the study, but many of these more mountainous areas can be successfully

converted, especially for wildlife habitat development purposes. Such areas are now being treated, but without the benefit of definite study criteria on which to base these operations. The ecology of these portions of the P-J type needs study as well as the flatter areas. Perhaps soils would have taken on greater significance as a controlling element in P-J ecology if these steeper areas with shallower soils had been included in the analyses.

In the vegetation composition tables of Section 3, such terms as "abundance classification" and "percent construction" should be defined. Otherwise, data interpretation will remain questionable. Certain other terms used elsewhere in the report are also subject to varying interpretations and should be clarified.

Section 4 presents a scheme for site quality classification through use of a tree index. This is the most questionable portion of the report. The rationale behind using a height/diameter index to reflect site productivity needs more detailed and clarifying discussion.

First, the objective in determining a site index is not clearly discernible from the information given. The impression is gained from report contents that this index is meant to relate to all possible biological products of the site. This appears to over-extend the capabilities of such an index. Usually forest site indices are related to volume increment of wood, and this may be an objective here. However, more attention seems

to be directed toward correlations with understory production. The report offers the speculation that tree site index should be a good expression of grass productivity, but such is not confirmed by the study.

The decision to offer only one site index for the entire P-J type, that being the height/diameter criterion for pinyon only, is viewed with uncertainty. The point is made in the report that the Coronado province out-produces the other two provinces in both trees and understory; however, when seeded to introduced species of grass the Escalante and LaSal provinces are far more productive than the Coronado. These circumstances present a series of questions concerning the proposed site quality index.

Using an overall index, it follows that a preponderance of the highest rating sites will fall in the Coronado province. If separate height/diameter curves had been provided for each province or subprovince, such rating discrepancies would no doubt have been evident. Since trees grow much more rapidly (as shown by the height/age and diameter/age curves) in the Coronado province than in the LaSal, height growth by the time 10-inch diameter is attained will probably be greater there also. Therefore, some degree of correlation perhaps exists between the height/diameter index and volume increment. This constitutes, at best, an indirect consideration of the indispensable production element of time. A direct involvement of tree age in the quality index would probably have been desirable, regardless of the problem injected by generally uneven-aged stands.

Even though there may be a correlation between index and volume growth of trees (although unproven in the study), the relation between index and seeded grass production must necessarily be erratic. Such plantings are not generally successful in the Coronado province. Index correlations with increased production response of understory species after tree removal is not elucidated even for the leveler sites of the P-J type studied. No evidence nor rationale is presented to back up the apparent assumption that a site index based on tree growth characteristics will satisfactorily predict herbaceous plant production.

Any feasible use of the pinyon site index presented would seem to be predicated on its separate derivation for each dissimilar physiographic or climatic region. The three provinces may not be adequate breakdown for this purpose; the subprovinces might. Even then the only hope of this being an adequately sensitive system to reflect productivity must be based on the assumption that tree height growth will accelerate at a greater relative rate with site quality increase than will diameter increment. Otherwise, the index (height/10" diameter) may tend to remain relatively constant for sites of different productivities.

A most helpful addition to the report from the point of view of reviewers would have been the plotting of actual field data on the various graphs. From plotted point dispersions, a better idea could have been obtained of data variability and validity of correlations. A table of correlated values taken from each of the graphs would also have been very helpful, since it is impossible to accurately take such information from the rough illustrations included in the report.

Section 5 presents a good development of soil site factors important in quality evaluation, and a very enlightening review of pertinent literature. The general study limitations on time and restriction of sampling to gentle slopes made inroads on the completeness of this phase of the study also. An additional bias was injected by taking soil samples from under the crowns of site trees. Other situations in P-J stands were not sampled.

Section 6 contains a lot of good information on tree characteristics in relation to control success and describes the means previously used in P-J control operations. Some good guides to predicting success of treatment are given, such as minimum required tree heights of 10 feet and the percent of 7 inch diameter trees and over needed.

The procedure derived for predicting longevity of conversion results was interesting. Here again, however, discrepancies in rates of tree growth in different ecological areas appears to require that specific derivations be made for each dissimilar area.

Section 7 presents a good analysis of range forage values based upon the limited data obtained. Careful attention is given to the inverse relation between tree crown cover and forage production, and it was interesting to note the difference in response of shortgrasses and bunchgrasses to tree cover.

The discussion of grass production resulting from three different conversion methods in the various provinces is most pertinent and presents

some definite physical guides for method of treatment after a decision is made to convert to a non-tree cover. (The economic criteria for conversion decisions are included in Part B of the study report.)

The hypothetical derivation of estimating equations for forage response is also an interesting proposal. However, the specific equations presented for each conversion method are of questionable validity since they are based on just one year's production data.

Section 8 is apparently based on the presumed conclusions of Part B of the study on economic considerations. It is assumed that, except for special cases, the best current use of the type is to provide forage for livestock and wildlife. Alternatives for management suggested are livestock use control and tree eradication to increase forage.

The recommended conversion criteria and discussion of treatment alternatives for each province are generally acceptable and should prove helpful in making P-J management decisions. The main deficiencies relate mostly to conversions for wildlife habitat and watershed protection and to restrictions against treating sites with over 15% slope. Some successful conversions on steeper areas with other favorable site qualities were being made at the time the study was in progress, and several have been successfully completed since. These involve shrub seedings as well as grass.

The other major point of critical interest is the indicated lack of correlation between herbaceous production and the proposed site quality index.

Section 9 includes volume tables prepared in Arizona and New Mexico some years ago by the SCS and some cursory information on various P-J woodland product uses. The volume tables would be usable where derived only, and the value of extending these by further data collection is questionable as explained in the report.

Of the products considered, only for Christmas trees was any substantial amount of data collected and only for this product is the recommendation made to extend product studies. This appears to be reasonable until better prospects for other economically feasible uses are developed.

Section 10 presents some possible criteria for a woodland inventory and a range production inventory suggestion. The woodland inventory procedures involve classifying P-J type areas for the various multiple uses. The proposals may be useful in establishing a basic management inventory system for such areas.

The range forage prediction system is interesting but presumes, among other things, that a valid correlation exists between site index and forage production.

The title of Part A, Ecology of the Pinyon-Juniper Type of the Colorado Plateau and the Basin and Range Provinces, implies a broad and comprehensive treatment of P-J ecology. This study is far from such a complete coverage. Imposed time limitations precluded the basic investigations that would necessarily have been included to identify and evaluate the physical and biological factors involved and their interactions. An analysis of historical changes in the type and the identification or development of conversion means to meet current and prospective future needs and use demands would all be part of such a study. It would require an extended period of time to complete a series of such basic investigations.

Part A had three expressed objectives. The first, to develop ecological criteria for classification of P-J sites, was met. A set of criteria is presented, although its extent and degree of development was limited by time allocation. The second objective, to develop the minimum essential ecological data needed for management under various alternatives, may be considered as met depending on decisions of management needs which apparently have not been made even yet. A fund of ecological data was amassed during the brief study; and, from a management point of view, it appears minimal. The last objective, to clearly identify the multiple products of woodland ranges, was met. These products were listed, and their relative importance implied by the extent each was treated. Interactions between these uses was not probed to any adequate extent. Again, such in-depth studies would involve results obtainable only over periods of time not here provided. It was apparently assumed that the competitive-complementary-supplementary relations would be covered in Part B on economic analyses.

This study was necessarily restricted to evaluations of existing P-J treatments and uses. This meant limiting field data collection to untreated P-J stands and sites converted to herbaceous cover. The lack of opportunity to make trial treatments and product studies as part of the research project appears to account for inadequate consideration of multiple use alternatives and products.

Additional light on the validity of the site quality index is needed, along with some manifestation of the statistical quality of the data collected and used in arriving at conclusions.

Mention has been made of the poor quality of many of the report's illustrations. The document also needs to be carefully edited to eliminate a variety of spelling, punctuation, and composition errors.

We hope this review constitutes a fair treatment of the report. We think it points up some problems of importance in adapting the findings for use as Bureau management guides. We regret that a more complete ecological study over an adequate period of time was not provided.

Table 10.a.1 continued.

Mapping unit	Map designation	Slope	Management alternations	Management limitations	Mapping unit (minimum)
			Woodland tree products 1. Fence posts 2. Christmas trees Wildlife Watersheds		
Non-managable sites	NM	$30\%^{+}$	Recreation 1. Scenic areas Wildlife Watershed		640 acres
Reserved sites	R	Varies	1. Areas reserved under existing administrative withdrawals		Varies with the type of withdrawal

*In this case inaccessible means one that could be developed by a proper road system. Areas that will always remain inaccessible should be designated NM.

Upon completion of a broad management classification of the pinyon-juniper woodlands, the next step would be to inventory the areas designated as multiple use and limited management sites.

Inventory methods-- In Tables 10.a.2 and 10.a.3 relationships developed in the present study, which could be utilized in inventory procedures, are displayed.

Table 10.a.2. Pinyon sp. relationships

Relationship	Site index				
	11'-17'	18'-23'	24'-31'	11'-20'	21'-31'
Ht/Cr diameter	-------Section 4 c-----------			------------------	
Ht/age (Figures)	6.c.1	6.c.1	6.c.1	10.a.1	10.a.1
Ht/diameter (Figures)	9.b.1	9.b.1	9.b.1	10.a.3	10.a.3
Volume tables	-------Section 9.a-----------			------------------	

Table 10.a.3. Juniper sp. relationships

Relationship	Site index				
	11'-17'	18'-23'	24'-31'	11'-20'	21'-31'
Ht/Cr diameter	--------Section 4.c---------			------------------	
Ht/age (Figures)	6.c.2	6.c.2	6.c.2	10.a.2	10.a.2
Ht/diameter (Figures)	9.b.2	9.b.2	9.b.2	10.a.4	10.a.4
Volume tables	--------Section 9.a---------			------------------	

The most suitable photo scale for woodland inventory would be 1:20,000; with this scale it would be possible to determine the tree heights and crown diameter of the dominant trees. It will also be possible to determine crown cover percentages in 5 percent intervals. Given tree heights, ages and diameters can be estimated. It is then a simple step to obtain volumes.

If suitable aerial coverage is not available, it will be necessary to obtain a generalized estimate of stand height and densities by using the best photos available as well as ground and aerial reconnaissance.

The following map designations for the inventory management sites are suggested (Table 10.a.4). The minimum mapping unit should remain the same as that suggested in Table 10.a.1.

Table 10.a.4. Suggested inventory management symbols

Crown Cover	Use with 1:20,000 photos			Use with scale greater than 1:20,000	
	Site indices			Site indices	
	11-17'	18-23'	24'-31'	11'-20'	21'-31'
1-20%	1/1	2/1	3/1	I/1	II/1
21'-40%	1/2	2/2	3/2	I/2	II/2
40% & above	1/3	2/3	3/3	I/3	II/3

Species designation should be
P: stands 80% and more pinyon
P-J: stands less than 80% of either species
J: stands 80% and more juniper

Proper diameter, age and volume associations can be employed for more detailed study and inventory of the sites that have been specifically selected for woodland management.

Recommendation-- Sufficient material has been developed in the present study to suggest the basic relationships necessary for a preliminary inventory of P-J woodlands. Sufficient field work should be carried out to refine the volume tables and to determine the best working procedures.

10.b. Range Inventory in Pinyon-Juniper Woodlands: A Suggestion -- R. J. Rivers and A. LeBaron

The purpose of this section is to consider some aspects of range inventory needs in pinyon-juniper woodlands. It is an extension of comments made on pages 163-164 *supra*. One suggestion is to experiment with aerial photos

Figure 10.a.l. Pinyon Height/Age Curves

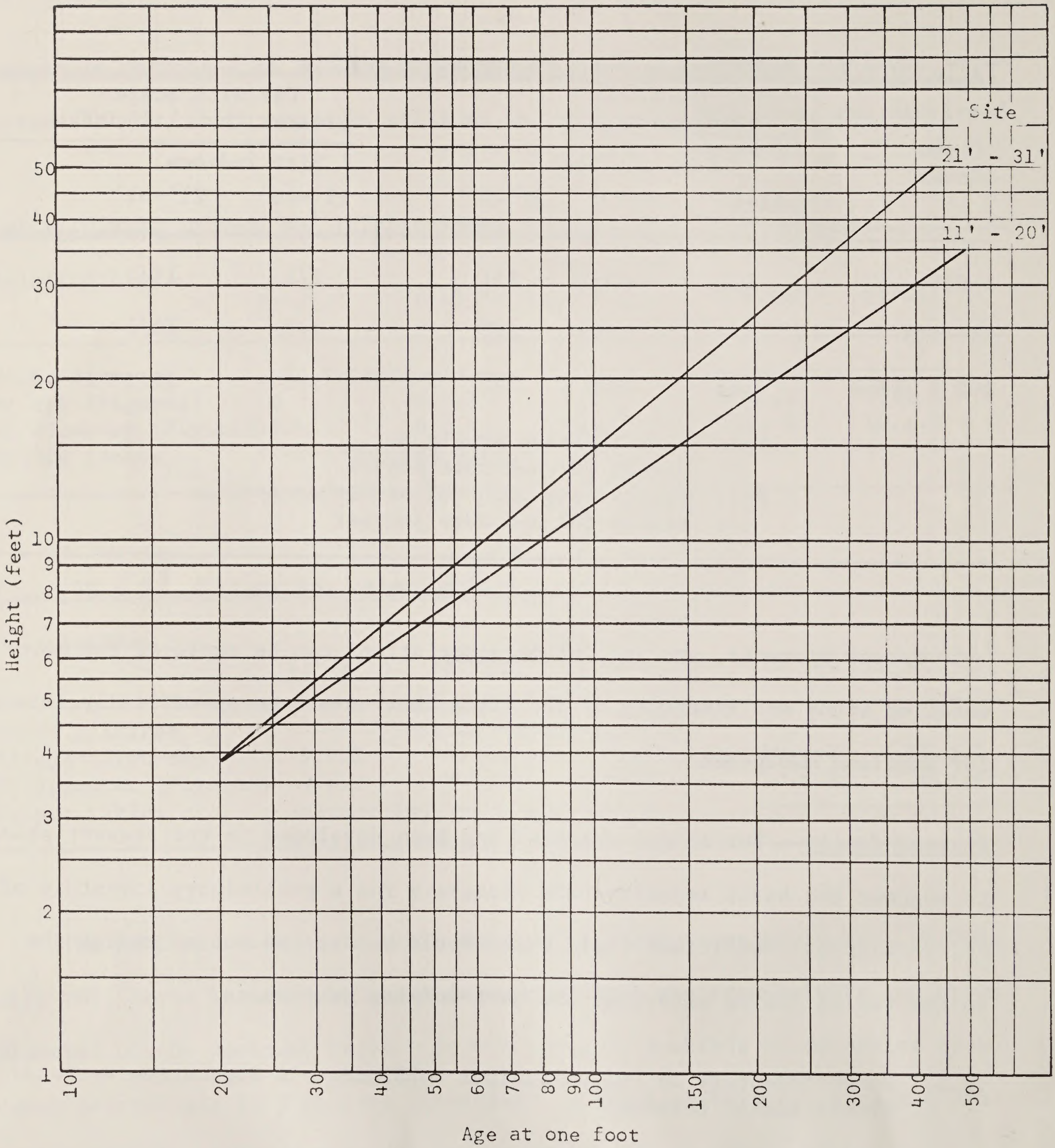


Figure 10.a.2. Juniper Height/Age Curves

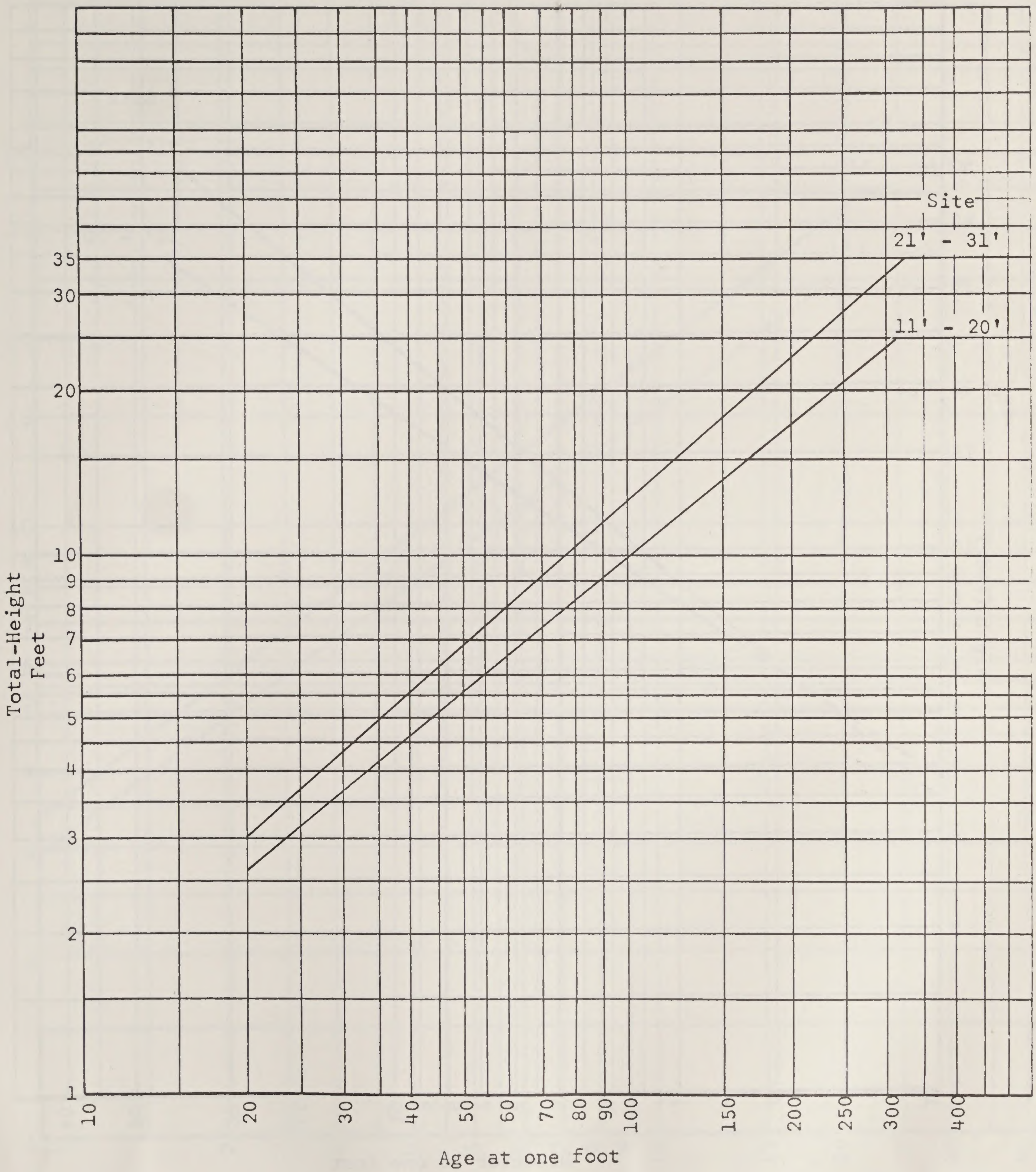


Figure 10.a.3. Pinyon Height/Diameter

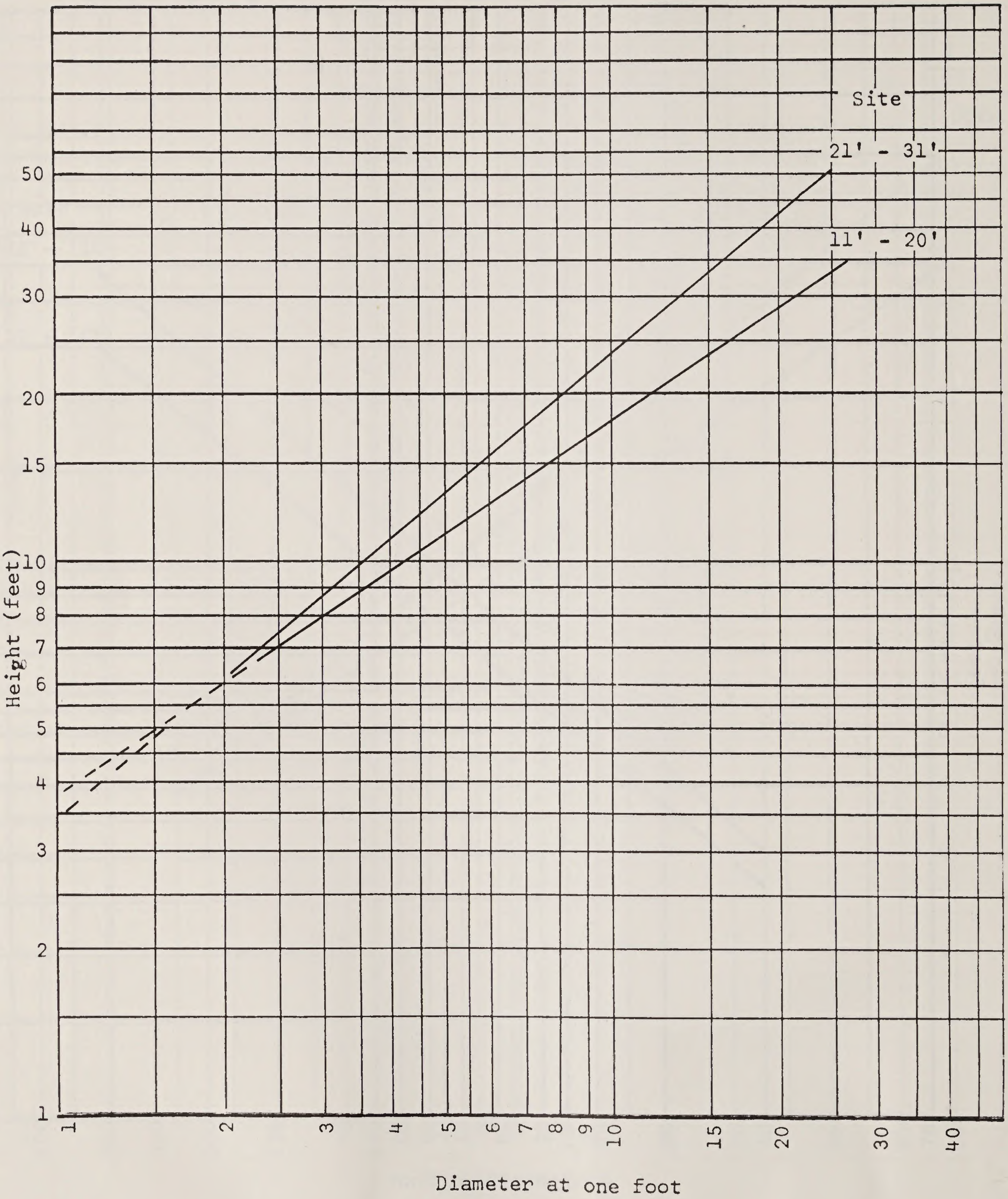
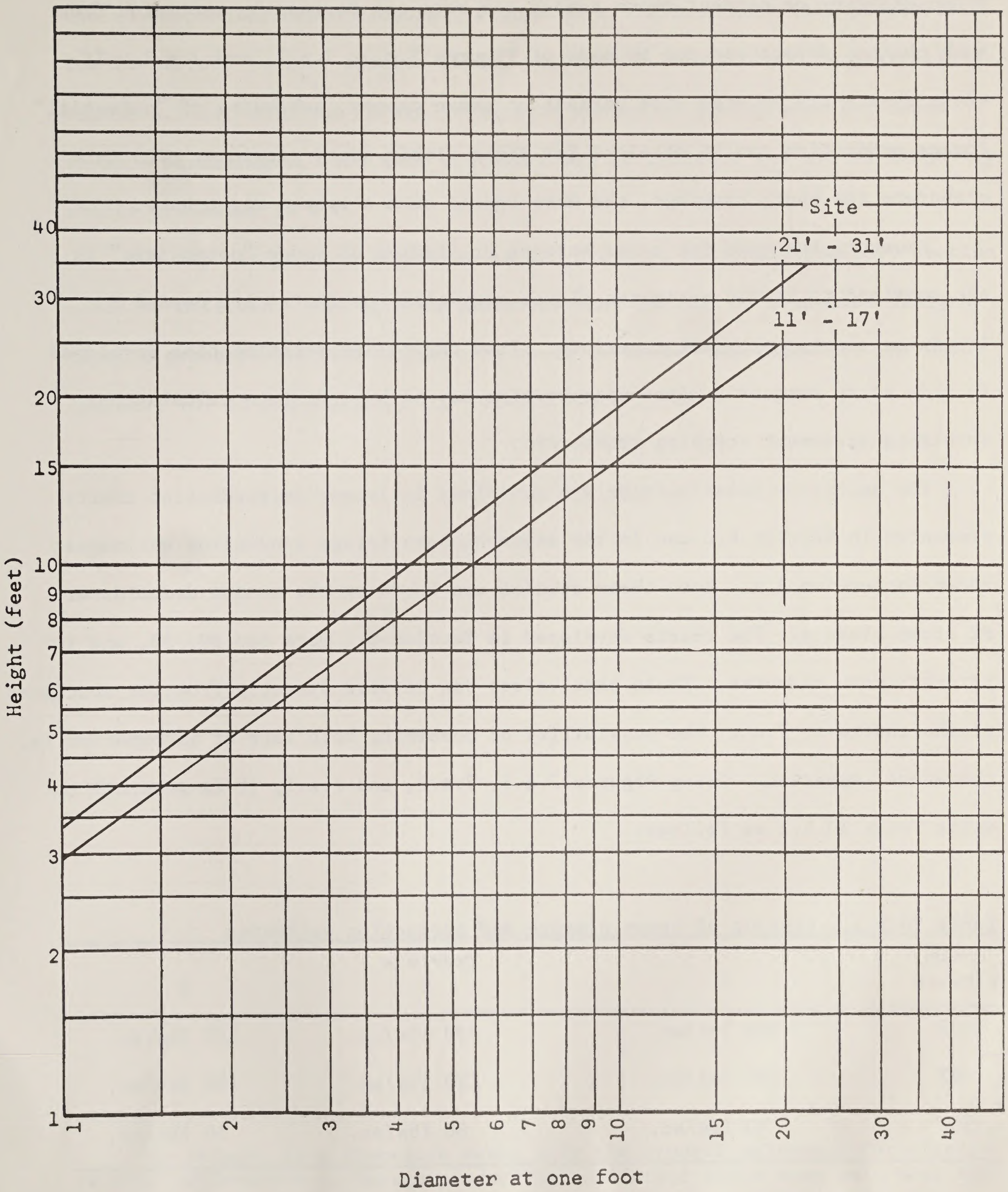


Figure 10.a.4. Juniper Height/Diameter



as an inexpensive means of surveying "potentials" for grass production. Since crown diameter or percent crown canopy per acre can be readily estimated from such photos, direct use can be made of Figures 7.a.1, 7.a.2, and 7.a.3. If these charts are entered with percent of crown canopy, estimates of "potential" forage production can be obtained for areas within every province. The more elaborate the photo coverage, the more appeal such a system might have.

However, the need for range surveys or studies of range "potentials" is not confined to static estimates alone; many times estimates are needed for longer or shorter management periods. Tree canopy/age relationships developed in this study suggest a means whereby time may be brought into calculations involving allotment stocking rates, etc.

The necessary relationships are contained in longevity/prediction charts presented in Section 6.c and in the crown-closure/forage production estimates shown in Section 7.a. Both these studies are based on the common denominator of crown closure. The charts developed in Section 6.c were for 50, 30, and 10 percent crown closures. These same values can be read directly from the abscissas of the charts in 7.a . The possibility of combining both sets of information is, therefore, apparent. Using Figures 7.a.1, 7.a.2, and 7.a.3, it is possible to write Table 10.b.1 as follows:

Table 10.b.1. Listing of crown closure and production estimates

Crown Closure	Province 1	 2	 3
10%	300 lbs/ac.	530 lbs/ac.	450 lbs/ac.
30%	100 lbs/ac.	230 lbs/ac.	190 lbs/ac.
50%	40 lbs/ac.	80 lbs/ac.	50 lbs/ac.

The next step is to enter the appropriate longevity/prediction chart and substitute the grass production estimate from Table 10.b.1 onto the curve for the corresponding crown closure. Figure 10.b.1 illustrates this procedure for 24-31 foot juniper species sites, province 2. This chart is basically Figure 6.c.6a, with the forage production estimates substituted for crown closure percentages. The same procedure may be followed for all 12 longevity charts presented in 6.c.[1]

The map designation suggested in the previous woodland inventory section could be utilized. The only variation is that instead of a species designation, a grass production designation would be used. For example: (A) 0-50 lbs/ac.; (B) 51-100 lbs/ac.; (C) 101-200 lbs/ac., etc.

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[1] In effect, this procedure makes only the crudest allowance for effects of site differences on forage production; different sites mean only that the "potential" will exist for varying lengths of time.

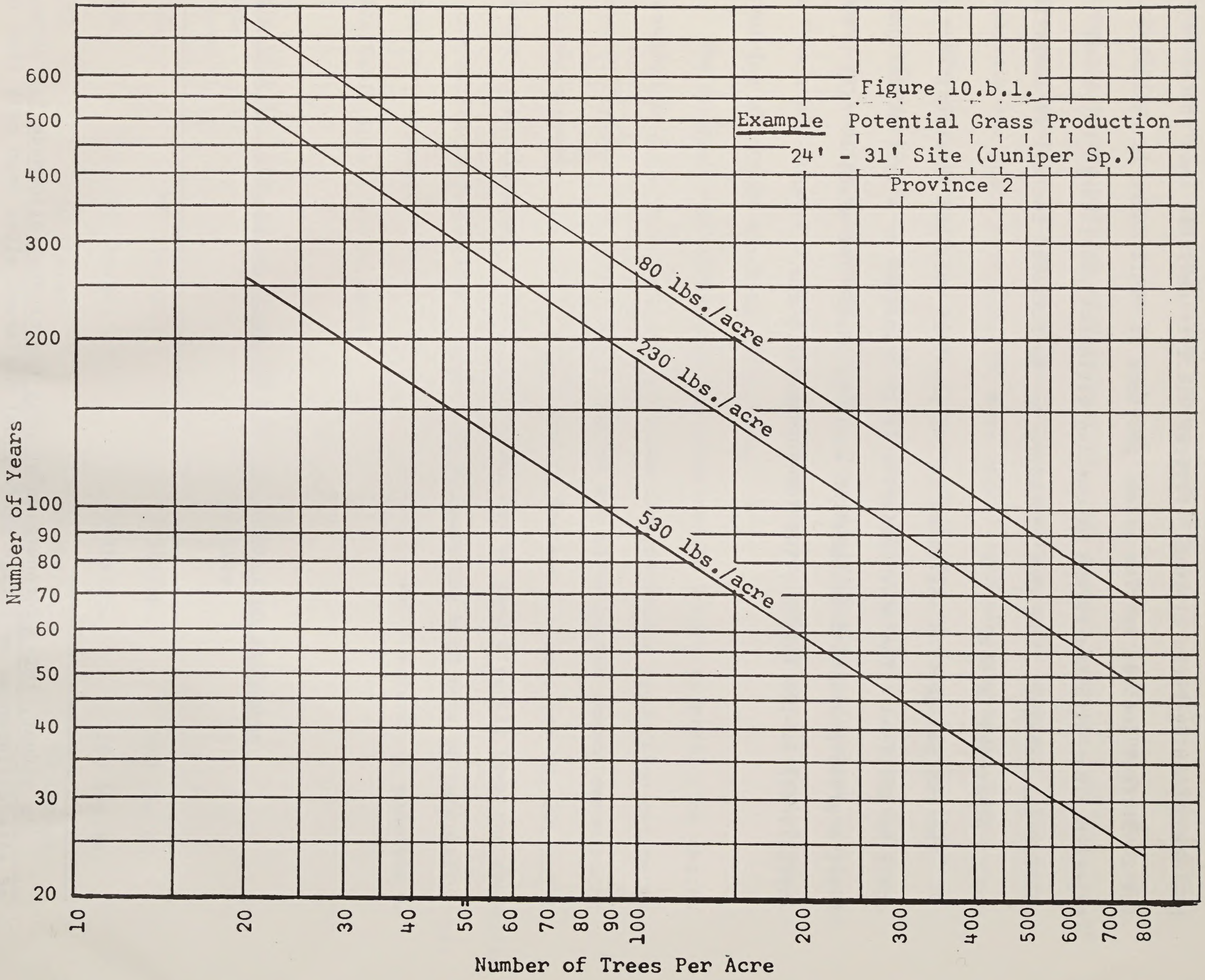

Figure 10.b.1.

Example Potential Grass Production

24' - 31' Site (Juniper Sp.)

Province 2